Academic Report – 2014–15

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 Institute's 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 Institute's 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. Kulkarni's 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 S.S. 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.

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 non-perturbative aspects of string theory and quantum field theory are being actively investigated. Research in neutrino physics, strong interactions, lattice gauge theory, supersymmetry and various aspects of physics beyond the standard model is done in high-energy phenomenology. The Institute is a member of the India-based Neutrino Observatory (INO) collaboration.

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 most newsworthy event for HRI last year was the award of the ICTP Dirac medal to Prof. Ashoke Sen. This is a singular achievement because no Indian scientist working in India has ever won this award. Prof. Jogesh Pati is the only other Indian to be given this medal but all his work has been done from the University of Maryland in U.S.A. Another notable achievement was that of Prof. Sukumar Das Adhikari who received the M.S. Singhal Memorial award of Indian Mathematical Science Congress.

As always, the year has seen a large number of conferences, workshops and schools in both physics and mathematics. There was a one month long advanced instructional school on combinatorics in April, 2014, a two weeks workshop on symplectic geometry and contact topology in December, 2014 and a conference on infinite dimensional Lie theory and its applications in mid December, 2014. In physics, there was a two weeks school on the very fashionable and fast changing world of topological quantum matter in February, 2015 and a quantum information school geared for young researchers towards the end of February, 2015.

A large number of prominent visitors came to the Institute in the course of the year. Some stayed for a longish while and delivered a course of lectures. Prof. Bettina Wilkins of University of Bostwana, South Africa, Prof. Kishore B. Marathe of City University of New York and Prof. Winfred Kohnen of Max Planck Institute for Astronomy in Germany delivered a course of three lectures each. Prof. Jaya Iyer of IMSc., Chennai and Prof. Manish Mishra of University of Heidelberg gave two lectures each. Prof. Valery Rubakov of the Russian Academy of Sciences was the speaker for the Triveni lecture for the year. A Harish-Chandra Memorial lecture for outreach purposes was established and the first lecture delivered by Prof. Charles Bennett of IBM Research Centre, Yorktown Heights. The Foundation day lecture was delivered by Prof. Shiraz Minwalla of TIFR, Mumbai.

The outreach activities of HRI flourished. The summer programme in mathematics (SPIM) was as popular as ever. A week long science programme in Hindi was conducted to help local students get a feel for scientific logic. The science talent search test in mathematics and physics was conducted as usual in November for students of 10th and 12th grade in the Allahabad area. A programme was organised for the top performers where a popular introduction to strings was given by Prof. Rajesh Gopakumar of HRI.

Future Programme

There has been a major rethinking by the faculty members about the future role of HRI. Having established itself as a premier research institution, it is felt that the excellent masters level teaching which is carried out for the Ph.D students who enter with a bachelor degree should be extended to students who want only a masters degree. Accordingly, an expansion scheme whereby the Institute becomes a full-fledged post graduate Institution running both a masters and a doctoral programme has been submitted to DAE for consideration. This envisages a doubling of the Institute faculty (from 40 to 80) in the next decade and a yearly intake of about 75-80 students. This should make HRI the leading Institution in physics and mathematics in the central part of India.

Jayanta Kumar Bhattacharjee
Director

List of Governing Council Members

(2014 -15)

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. Mr. Pranay Kumar Verma
   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. Shri 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
    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 Umesh Kumar Singh [Store/Purchase Officer]
21. Shri P.N. Mishra [Jr. Lib. Assistant]
22. Shri D.P. Sharma [Jr. Lib. Assistant]
23. Shri Sanjeev Nagar [Hindi Typist]

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

Visiting Fellow

Mathematics

1. Dr. Vipul Kakkar
2. Dr. Makoto Sakagaito
3. Dr. Varun Dilip Thakre
4. Dr. Abhitosh Upadhyay
5. Dr. Jitender Kumar
6. Mr. Dipendu Maity
7. Mr. Shailesh Trivedi

Physics

1. Dr. Madhuparna Karmakar
2. Dr. Arindam Chatterjee
3. Dr. Ambresh Kumar Shivaji
4. Shri Trilochan Bagarti
5. Dr. Debraj Rakshit
6. Dr. Abhishake Sadhukhan
7. Dr. Arghya Choudhury
8. Mrs. Soumini Chaudhury
9. Ms. Priyanka Mohan
10. Dr. Sourav Bhattacharya
11. Dr. Kouhei Hasegawa
12. Dr. Anindya Biswas
13. Mr. Nilay Kundu
14. Dr. Menika Sharma

15. Dr. Suprabh Prakash
16. Dr. Tanumoy Mandal
17. Dr. Namrata Shukla
18. Dr. Masazumi Honda
19. Dr. Amit Kumar Pal
20. Mr. Subhadeep Mondal
21. Dr. Masaki Murata
22. Mr. Himadri Shekhar Dhar
23. Mr. Debajyoti Dutta
24. Mr. Nandan Roy
25. Mr. Samyadeb Bhattacharya
26. Dr. Dheeraj Kumar Singh
27. Mr. Dushyant Kumar

Visiting Scientist

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

Research Scholar

Mathematics

1. Mr. Jay Gopalbhai Mehta
2. Mr. Akhilesh P.
3. Mr. G. Kasi Viswanadham
4. Mr. Pradeep Kumar Rai
5. Ms. Eshita Mazumdar
6. Mr. Divyang G. Bhimani
7. Mr. Senthil Kumar K.
8. Mr. Ramesh Manna
9. Ms. Sneh Bala Sinha
10. Mr. Balesh Kumar
11. Mr. Bibekananda Maji
12. Ms. Debika Banerjee
13. Mr. Mallesham K
14. Mr. Pallab Kanti Dey
15. Mr. Rahul Kumar Singh
16. Mr. S. Manikandan
17. Mr. Bhuwanesh Rao Patil
18. Mr. Arvind Kumar
19. Mr. E. Pramod
20. Mr. Manish Kumar Pandey
21. Mr. Nabin Kumar Mehar
22. Mr. Pradeep Das

23. Mr. Anup Kumar Singh
24. Mr. Mithun Kumar Das
25. Ms. Sumana Hatui
26. Ms. Ritika Sharma
27. Mr. Tusar Kanta Naik
28. Mr. Soumyarup Banerjee
29. Mr. Anoop Singh
30. Mr. Veekesh Kumar

Physics

1. Mr. Manoj Kumar Mandal
2. Mr. Saurabh Pradhan
3. Mr. Nyayabanta Swain
4. Mr. Abhishek Chowdhury
5. Mr. Swapnamay Mondal
6. Ms. Akansha Singh
7. Ms. Shrobona Bagchi
8. Mr. Mehedi Masud
9. Mr. Avijit Misra
10. Mr. Maguni Mahakhud
11. Ms. Avinanda Chaudhuri
12. Mr. Utkarsh Mishra
13. Ms. Ushoshi Maitra
14. Mr. Aritra Gupta
15. Mr. Abhishek Joshi

16. Mr. Shankha Banerjee
17. Mr. Uttam Singh
18. Mr. Kadge Samrat Suresh
19. Mr. Dibya Kanti Mukherjee
20. Mr. Arijit Dutta
21. Mr. Sauri Bhattacharya
22. Mr. Tamoghna Das
23. Mr. Krashna Mohan Tripathi
24. Mr. Asutosh Kumar
25. Mr. Debasis Mondal
26. Mr. Nabarun Chakrabarty
27. Mr. Aditya Banerjee
28. Mr. Udit Khanna
29. Ms. Arpita Sen
30. Ms. Ajanta Maity
31. Mr. Harshant Singh
32. Mr. Debasis Sadhukhan
33. Mr. Sudipto Singha Roy
34. Mr. Mritunjay Kumar Verma
35. Mr. Sitender Pratap Kashyap
36. Ms. Juhi Dutta
37. Mr. Titas Chanda
38. Mr. Subhroneel Chakrabarti
39. Mr. Satadal Datta
40. Mr. Jyotiranjan B.

41. Mr. Kasinath Das
42. Mr. Rishu Kumar Singh
43. Ms. Ruchi Saxena
44. Md. Arif Shaikh
45. Mr. Siddharth Dwivedi
46. Mr. Gautam Sharma
47. Mr. Chiranjib Mukhopadhyay
48. Mr. Ritabrata Bhattacharya
49. Mr. Sarif Khan
50. Mr. Dhruv Pathak
51. Mr. Shouvik Roychoudhury
52. Ms. Sreetama Das
53. Mr. Dipyaman Pramanik
54. Mr. Sandeep Kumar Sehrawat
55. Mr. Samiran Roy
56. Mr. Abhass Kumar
57. Mr. Biswajit Sahoo
58. Ms. Tanaya Ray
59. Mr. Soumyananda Goswami
60. Mr. Saptarshi Roy
61. Mr. Khorsed Alam
62. Mr. Avirup Ghosh
63. Mr. Ratul Mahanta

Academic Report - Mathematics

Sukumar Das Adhikari

Research Summary:

Continuing work on some zero-sum problems in additive combinatorics and some other related extremal problems in combinatorics. New results have been obtained in the area of zero-sum problems with weights. Work is in progress on some questions of monochromatic solutions of certain equations.

Publications:

1. Sukumar Das Adhikari, Weidong Gao and Guoqing Wang, *Erdős-Ginzburg-Ziv theorem for finite commutative semigroups,* Semigroup Forum, 88, Issue 3, 555–568, (2014).

2. Sukumar Das Adhikari and Eshita Mazumdar, *Modifications of some methods in the study of zero-sum constants,* Integers, 14, paper A 25, (2014).

3. Sukumar Das Adhikari and Yong-Gao Chen, *On monochromatic configurations for finite colorings*, Discrete Mathematics, Vol. 333, 106–109 (2014).

4. 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., To appear.

5. Sukumar Das Adhikari and Eshita Mazumdar, *The polynomial method in the study of zero-sum theorems,* Int. J. Number Theory, To appear.

Conference/Workshops Attended:

1. *The twelfth annual workshop on combinatorial and additive number theory (CANT 2014)*, CUNY Graduate Center, New York, May 27- 30, 2014.

2. *Bateman-Halberstam Conference*, University of Illinois, Urbana - Champaign, June 1-7, 2014.

3. *International Conference on Current Developments in Mathematics and Mathematical Sciences (ICCDMMS-2014)*, Asutosh Bhavan, Salt Lake City, Kolkata, December 19-21, 2014.

4. *Two-day Mathematics Workshop celebrating the National Mathematics Day*, Allahabad (NASI Headquarters), Dec 22-23, 2014.

5. *National Conference on Algebraic Number Theory and Modular Forms*, Savitribai Phule Pune University, January 2-3, 2015.

6. *Discussion Meeting on Analytic Number Theory 2015*, Tata Institute of Fundamental research, Mumbai, January 5-9, 2015.

Visits to other Institutes:

1. Department of Mathematics, Ohio State University, Columbus, Ohio, May 2014.

2. CUNY Graduate Center, New York, May 2014.

3. University of Illinois, Urbana - Champaign, June 2014.

4. Ramakrishna Mission Vivekananda University, Belur, India, July 2014 and Feb-March, 2015.

5. Chennai Mathematical Institute, September 2014.

6. Departamento de Matemática Aplicada I, Universidad de Sevilla, Spain, October 2014.

7. Tata Institute of Fundamental research, Mumbai, January 2015.

Invited Lectures/Seminars:

1. *A classical zero-sum theorem in combinatorial number theory: some recent generalizations*, Combinatorics seminar, Department of Mathematics, Ohio State University, Columbus, Ohio, May 27, 2014.

2. *Some generalizations of certain zero-sum theorems: recent progress*, The twelfth annual workshop on combinatorial and additive number theory (CANT 2014), CUNY Graduate Center, New York, May 30, 2014.

3. *Some zero-sum problems in Combinatorial Number Theory*, Bateman-Halberstam Conference, University of Illinois, Urbana - Champaign, June 1-7, 2014.

4. *Two applications of van der Waerden's theorem and some related questions*, Chennai Mathematical Institute, September 2014.

5. *A course of lectures on Combinatorial Number Theory*, Departamento de Matemática Aplicada I, Universidad de Sevilla, Spain, October 20-24, 2014.

6. *An early zero-sum theorem in additive combinatorics*, Suddhodan Ghosh Memorial Lecture, at the International Conference on Current Developments in Mathematics and Mathematical Sciences (ICCDMMS-2014), Calcutta Mathematical Society, Asutosh Bhavan, Salt Lake City, Kolkata, December 19-21, 2014.

7. *Zero-sum theorems in additive combinatorics*, Two-day Mathematics Workshop celebrating the National Mathematics Day, Allahabad (NASI Headquarters), Dec 22-23, 2014.

8. *Zero-sum theorems: Some algebraic methods*, Discussion Meeting on Analytic Number Theory 2015, Tata Institute of Fundamental research, Mumbai, January 5-9, 2015.

Academic recognition/Awards:

- Currently, an Adjunct Professor in the Department of Mathematics in Ramakrishna Mission Vivekananda University, Belur.

- Received the M K Singhal Memorial Award for the year 2013-14 by the Indian Science Congress Association.

Other Activities:

1. Currently Dean, Administration at HRI.

2. Member of 'the National Board for Higher Mathematics' (NBHM).

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. Was one of the organizers of the AIS school on ‘Combinatorics’ held at HRI during 28th April, 2014 to 17th May, 2014 and gave a course of lectures in this programme.

8. Gave a course on group theory at SPIM 2014 in June 2014 at HRI.

9. Gave a course to the M. Sc students at RKMV University, Belur, during July 12 -23, 2014 and another one during Feb-March, 2015.

10. Was one of the organizers of ATM Workshop on ‘Topological Combinatorics’ held at HRI during October 6-11, 2014 and gave a talk in the workshop.

Ramakrishnan Balakrishnan

Research Summary:

1. Convolution sums of the divisor functions and its applications (with Brundaban Sahu). In this ongoing work, we use the theory of quasimodular forms and the theory of modular forms to evaluate certain convolution sums involving the divisor functions $\sigma(n)$ and $\sigma_3(n)$. These convolution sums are then used to get formulas for the number of representations of an integer as a sum of 8, 12 and 16 squares and also the number of representations of certain quadratic forms in 12 and 16 variables. Work on triple convolution sums of the divisor functions is also in progress.

2. Theory of newforms of half-integral weight (with M. Manickam and Jaban Meher) In this revised version of our earlier work, we set up the theory of newforms of half-integral weight on $\Gamma_0(8N)$ and $\Gamma_0(16N)$, where N is odd square-free. Further, we extend the defintion of the Kohnen plus space in general for trivial character and also study the theory of newforms in the plus spaces on $\Gamma_0(8N)$, $\Gamma_0(16N)$, where N is odd and square-free. Finally, we show that the Atkin-Lehner W-operator W_4 acts as the identity operator on $S_{2k}^{new}(4N)$, where N is odd and square-free. This proves that $S_{2k}^{-}(4) = S_{2k}(4)$.

Publications:

1. B. Ramakrishnan and Brundaban Sahu, *On the number of representations of an integer by certain quadratic forms in sixteen variables,* Int. J. Number Theory **10**, 1929–1937, (2014)

2. Soumya Das and B. Ramakrishnan, *Jacobi forms and differential operators,* J. Number Theory **149**, 351–367, (2015)

3. M. Manickam, Jaban Meher and B. Ramakrishnan, *Theory of newforms of half-integral weight,* Pacific J. Math. **274**, 125–139, (2015)

Preprints:

1. B. Ramakrishnan and Brundaban Sahu, *Convolution sums of the divisor functions and the number of representations of an integer by certain quadratic forms in twelve and sixteen variables,* preliminary version

Conference/Workshops Attended:

1. *RMS Number Theory Symposium*, Pune, India, June 2014.
2. *Discussion Meeting on Analytic Number Theory*, Mumbai, India, January 2015.

Visits to other Institutes:

1. The Institute of Mathematical Sciences, Chennai, India, Oct/Nov 2014.
2. Kerala School of Mathematics, Kozhikode, India, Feb 2015.

Invited Lectures/Seminars:

1. *Representation numbers of certain quadratic forms and convolution sums*, Two-day workshop on Mathematics-Celebrating the National Maths Day, National Academy of Sciences, India, Allahabad, December 2014.

Other Activities:

1. Oragnised and delivered lectures in the AFS II programme conducted by NCM at KSOM, Kozhikode, May 2014.
2. Invited to deliver lectures in the 'Winter School on Modular Forms' oraganised at Goa University, December 2014.
3. One of the organisers and one of the main speakers of the 'Workshop on Jacobi forms and modular forms of half-integral weight' organised at KSOM, Kozhikode, February, 2015.

Punita Batra

Research Summary:

In a joint work with S.E. Rao, irreducible, integrable highest weight modules for current Kac-Moody algebras have been classified. In another joint work with S.E. Rao, integrable modules for the twisted full toroidal Lie algebras have been classified.

Publications:

1. Punita Batra and Hiroyuki Yamane, *Skew centers of rank-one generalized quantum groups, To appear in Toyama Mathematical Journal, Proceedings of Tsukuba Workshop on Infinite Dimensional Lie Theory and Related Topics, October 20-23, 2014.*

Preprints:

1. S. Eswara Rao and Punita Batra, *Classification of irreducible integrable highest weight modules for current Kac-Moody algebras, Submitted.*

2. S. Eswara Rao and Punita Batra, *On integrable modules for the twisted full toroidal Lie algebra.*

Conference/Workshops Attended:

1. CBMS Conference on Higher Representation Theory at North Carolina State University, USA, July 6-10, 2014.

2. Young Women and Mathematics-2014 at IISER Pune, July 26, 2014.

3. Tsukuba Workshop on Infinite-Dimensional Lie Theory and related Topics at University of Tsukuba, Ibaraki, Japan, October 20-22, 2014.

Visits to other Institutes:

1. Department of Mathematics, North Carolina State University at Raleigh, USA during July 5-10, 2014.

2. IISER, Pune on July 26, 2014.

3. University of Tsukuba, Japan during October 19-22, 2014.

Invited Lectures/Seminars:

1. *The irreducible modules for the derivations of the rational quantum torus*, CBMS Conference on Higher Representation Theory at North Carolina State University, USA, July 9, 2014.

2. *Mini Course consists of two talks on "Basics of Lie algebras" and "Representations of $sl(2, F)$"*, IISER Pune, July 26, 2014.

3. *The irreducible modules for the derivations of the rational quantum torus*, Tsukuba Workshop on Infinite-Dimensional Lie Theory and related Topics at University of Tsukuba, Japan, October 20, 2014.

Other Activities:

1. Gave two lectures in the Rajbhasha scientific workshop at HRI in May 2014.

2. Gave two lectures in the "Hands-on training in Mathematics" for secondary school students at HRI on June 6, 2014. This programme was organised by NASI, Allahabad under Science Communication Programme.

3. Gave six lectures on " Ring Theory" in Summer Programme in Mathematics(SPIM) at HRI in June, 2014. I was one of the coordinator's of SPIM 2014.

4. Organised a conference on "Infinite dimensional Lie Theory and its Applications" at HRI during December 15-20, 2014.

5. Convener of the Sports and Entertainment Committee and Mathematics Visitor's Committee at HRI. Also serving as a member in the Rajbhasha Committee.

Kalyan Chakraborty

Research Summary:

Hafner and Stopple proved a conjecture of Zagier relating to the asymptotic behavior of the inverse Mellin transform of the symmetric square L-function associated to Ramanujan tau function. Jointly with B. Maji and S. Kanemitsu, we prove a similar result for any cusp form.

Riemann's non-differentiable function and Gauss's quadratic reciprocity law have attracted the attention of many researchers. In a joint work with S. Kanemitsu and H.-L.Li we provide a combined proof of both the facts. We use an integrated form of the theta function and the advantage of that is that while the theta-function $\Theta(\tau)$ is a dweller in the upper-half plane, its integrated form $F(z)$ is a dweller in the extended upper half-plane including the real line, thus making it possible to consider the behavior under the increment of the real variable, where the integration is along the horizontal line

The Selberg type divisor problem refers to raising the Dirichlet series to a complex power and studying the coefficients. The original objective of Selberg was to apply the results to the prime number theorems. However, the complex powers turn out to be of independent interest and have applications in studying the mean values of the L-functions. In a joint work with S. Kanemitsu and A. Laurinčikas for normalized holomorphic Hecek eigen cusp forms of the same weight, we consider the corresponding zeta-function (Dirichlet series) a là Hecke. We continue the research started A. Laurinčikas and I. Steuding on the summatory function of the complex power of the Dirichlet convolution of the coefficients of the cusp form zeta-functions. This has nice application in the study of 'integers without large and small prime factors'.

In another joint work along with B. Maji and S. Kanemitsu, we are working on a method of extracting the essential main term from the data on generating functions. For example, generating fundtion $F(s)$ may have an Euler product of a known zeta function. If the coefficient of the first order prime is $z = z + O(p^{-\delta})$ with an appropriate allowance element δ then we factor out the Euler product $\prod_p \left(1 - \frac{1}{p^s}\right)^{-z}$, which is $\zeta(s)^{-z}$. By appealing to the rich information on the extracted essential zeta-function, we may establish some interesting results for the original generating function. Especially on the asymptotic formula for the summitry function.

Publications:

1. Kalyan Chakraborty and Jay Mehta, *Preventing unknown key-share attack using cryptographic bilinear maps,* Journal of Discrete Mathematical Sciences and Cryptography **17, No.2**, 135–147, (2014)

2. K. Chakraborty, S. Kanemitsu and T. Kuzumaki, *On the Barnes multiple gamma functions,* Šiauliai Mathematical Seminar **9, No. 17**, 27–41, (2014)

3. Kalyan Chakraborty and Makoto Minamide, *On Power moments Of The Hecke Multiplicative Functions,* J. Aust. Math. Soc. (First Published online 2015) doi: 10.1017/S1446788715000063, 1–7, (2015)

4. Kalyan Chakraborty, Shigeru Kanemitsu and Y. Sun, *Codons and Codes,* Pure and Applied Mathematics Journal **4; 2-1**, 25–29, (2015)

5. Tomihiro Arai, Kalyan Chakraborty and Jing Ma, *Applications of the Hurwitz-Lerch zeta-function,* Pure and Applied Mathematics Journal **4; 2-1**, 30–35, (2015)

Preprints:

1. K. Chakraborty, S. Kanemitsu and H. Tsukada, *Applications of the Beta-Transform,* To appear in Šiauliai Mathematical Seminar

2. Tomihiro Arai, Kalyan Chakraborty and Shigeru Kanemitsu, *On Modular Relations,* Series on Number Theory and Its Applications, **Vol. 11**, (Plowing and Starring Through High Wave Forms); Forthcoming (March 2015), Proceedings of the 7th China–Japan Seminar, World scientific

3. K. Chakraborty, S. Kanemitsu and H. Tsukada, *Ewald expansions of a class of zeta-functions,* In preparation

4. B. Maji, K. Chakraborty and S. Kanemitsu, *Modular relations associated to the Rankin-Selberg L-functions,* In preparation

5. K. Chakraborty, S. Kanemitsu and H. -L. Li, *Quadratic reciprocity and Riemann's non differentiable function,* In preparation

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

7. B. Maji, K. Chakraborty and S. Kanemitsu, *Extracting a proper main term*, In preparation

Conference/Workshops Attended:

1. *Workshop on Number Theory and Its Applications*, China, November 2014.

2. *One Day Number theory seminar*, China, October 2014.

Visits to other Institutes:

1. Beijing University of Mining and Technology, Beijing, China, October 2014,

2. North West University, Xian, China, November 2014.

3. HongKong University, HongKong, November 2014.

4. Pt. Ravi Shankar Shukla University, Raipur, India, December 2014.

Invited Lectures/Seminars:

1. *Factoring Algorithms*, Workshop on Cryptography, MNNIT, Allahabad, July 2014.

2. *Introduction to cryptography*, Number Theory seminar, Beijing Institute of Mining and Technology, Beijing, October 2014.

3. *Class number formula for certain real quadratic fields*, Workshop of Number Theory and Its applications, North West University, Xian, November 2014.

4. *On the partial sum of spectral analogue of Mobius function*,Number Theory seminar, HongKong university, HongKong, November 2014.

5. *Modular Arithmetic*, INSPIRE CAMP, Pt. Ravi Shankar Shukla University, Raipur, December 2014.

6. *A Stroll in The Prime Garden*, INSPIRE CAMP, Pt. Ravi Shankar Shukla University, Raipur, December 2014.

Other Activities:

1. NBHM M.A./M.Sc. Fellowship – Written Test and Interviews, October–November, 2014.
2. NBHM Ph.D. Fellowship– Written Test and Interviews, February–March, 2015.

Chandan Singh Dalawat

Research Summary:

Let F be a finite extension of $\mathbf{Q}_p$ (where p is a prime number) and E a finite galoisian extension of F. The group $\mathrm{Gal}(E|F)$ comes equipped with a natural filtration, the ramification filtration in the lower numbering, and natural embeddings of the successive quotients. We determine the group $\mathrm{Gal}(E|F)$, its ramification filtration, and the embeddings of the successive quotients when E is the compositum of all degree-p extensions of F. It should be noted that in this case the group $\mathrm{Gal}(E|F)$ is neither tamely ramified nor commutative. Recall that the classification of the tamely ramified or abelian extensions of F is well-known.

Publications:

1. *Classical reciprocity laws*, Asia Pacific Mathematics Newsletter, **4** (4), 5–9 ; cf. `arXiv:1406.1857`.

Preprints:

1. *Eight lectures on quadratic reciprocity*, 51 pages, `arXiv:1404.4918`

Conferences/Workshops Attended:

1. *p-adic aspects of modular forms*, IISER, Poona, 10–19 June, 2014.
2. *Quadratic forms*, IISER, Mohali, 19–21 June, 2014.
3. *International congress of mathematicians*, Seoul, 13–21 August, 2014.
4. *Algebraic Number Theory and related topics*, RIMS, Kyoto, 1–5 December 2014.
5. *AIMS-Stellenbosch University Number Theory Conference*, Muizenberg and Stellenbosch, 19–23 January, 2015.

Visits to other Institutes:

1. Indian Institute of Science, Bangalore, 28 April – 7 May, 2014.
2. The Institute of Mathematical Sciences, Madras, 8–16 May 2014.

3. Research Institute for Mathematical Sciences, Kyoto, 8 September – 7 December 2014.

4. Tata Institute of Fundamental Research, Bombay, 6–11 Februay 2015.

Invited Lectures/Seminars:

1. *Roots of unity, or a sum worthy of Gauß*, Indian Institute of Science, Bangalore, 6 May 2014 ; The Institute of Mathematical Sciences, Madras, 15 May 2014.

2. *The general reciprocity law*, Benares Hindu University, 3 June 2014.

3. K_2 *and* H^2, IISER Mohali, 20, 21 June 2014.

4. *Some refined mass formulæ*, Osaka University, 31 October, Chuo University, 14 November, Kyoto University, 21 November, Kyushu University, 28 November 2014.

5. *One hundred years of Ramanujan's* τ, National Mathematics Day, 22 December 2014, `http://youtu.be/f-qJJ-bXWDA`

6. *Some refinements of Serre's mass formula*, African Institute for Mathematical Sciences – Stellenbosch University Number Theory Conference, 21 January 2015.

Other Activities:

Acted as Mentor for the Inspire Science Camp (DST) at Naini. Examined the thesis of a doctoral candidate from IIT Bombay and acted as the external examiner. Examined the doctoral thesis of a candidate from the University of Poona. Mentored an undergraduate student from an engineering college in Coimbatore, one from IIT Madras, one from IIT Kanpur, one from IMA Bhuvaneshwar, and two from IISER Mohali. Refereed some papers for international journals. Refereed a grant application for the Royal Society (London). Refereed a book proposal for Cambridge University Press. Acted as a guide for a one-semester project by an undergraduate student from IIT Kanpur.

Rukmini Dey

Research Summary:

Together with my student, Rahul Kumar Singh, I finalized a paper on rotational and helicoidal surfaces in R^3 locally bianalytically equivalent to algebraic surfaces. I continued my work with Pradip Kumar and Rahul Kumar Singh on interpolation between two real analytic curves by piecewise minimal surfaces. I continued my work on geometric quantization of the finite Toda systems. I also finalized a paper on Ramanujan's identities, minimal surfaces and solitons.

Together with Varun Thakre, I am embarked on a project of studying generalized Seiberg-Witten equations reduced to dimension 2 and also a project of exploring ways of viewing many equations coming from physics as integrable systems, for instance the vortex equations, Feuter equations etc.

Publications:

1. Indranil Biswas, Saikat Chatterjee, Rukmini Dey *Geometric prequantization on the path space of a prequantized manifold,* IJGMMP **vol 12, Issue 3**, page 1550030, (2015)

Preprints:

1. R. Dey, P. Kumar, R. K, Singh, *Piecewise minimal surfaces interpolating between two real analytic curves,* (in preparation)
2. R.Dey, R.K. Singh,, *Rotational and helicoidal surfaces locally bi-analytically equivalent to algberaic surfaces* (in preparation)
3. R.Dey, D. Jatkar, S.K. Paul, *Geometric Quantization of Hamiltonians in finite Toda system* (in preparation)
4. R. Dey, *Ramanujan's identities, minimal surfaces and solitons* (in preparation)

Conference/Workshops Attended:

1. *Symplectic geometry and Contact Topology, HRI* , India, Dec 2014

2. *Advanced school on Symplectic Geometry and Contact Topology , TIFR Mumbai*, India, Dec 2014.

Visits to other Institutes:

1. RRI , Bangalore, India, May-June 2014,

2. ICTS, Bangalore, India, May-June 2014.

3. TIFR, Mumbai, India , Dec 2014

Invited Lectures/Seminars:

1. *Geometric Quantization of Various Moduli Spaces*, ICTS, Bangalore, Sept 2014.

2. *Geometric Quantization and Coherent States*, IISC, Bangalore, June 2014.

3. *Geometric Quantization and Coherent States*, RRI, Bangalore, May 2014.

4. *Constant Mean Curvature Surfaces*, IISC, Bangalore, May 2014.

5. *Constant Mean Curvature Surfaces*, RRI, Bangalore, May 2014.

Other Activities:

1. Organizer (jointly with Mahan Mj, Indranil Biswas, R. Thangadurai), Symplectic and Contact Topology, HRI, Dec 1-12th, 2014.

2. Instructor, Topology II, HRI, August-December, 2014

D. Surya Ramana

Research Summary:

In earlier work with J. Cilleruelo and O. Ramaré, we obtained essentially optimal lower bounds for the cardinality of A/A, the set of ratios of integers all belonging to a large subset A of the integers in a given interval of the natural numbers. In the first preprint listed below, we extend our result in various directions. We study the cardinalities of A/A and that of the product set $A.A$ for a random subset of a prescribed density of the integers in a interval. We then study these quantities when A is a dense subset of the shifted primes and the set of sums of two squares.

In the second preprint listed below, with O. Ramaré, we obtain an exact formula for the error term of the Perron summation formula for short sums (without absolute value). As a consequence, we show, under the Generalised Riemann Hypothesis, that for any $\delta, \theta > 0$ almost every prime in the $[Q, 2Q]$ has the expected number of primitive roots in the interval $[x, x^{\frac{1}{2}+\delta}]$, when $Q \leq x^{\frac{2}{3}-\theta}$.

Publications:

1. P. Akhilesh and D.S. Ramana, *A Chromatic Version of Lagrange's Four Squares Theorem,* Monasthefte für Mathematik **176**, 17-29, (2015)

Preprints:

1. J. Cilleruelo, D. S. Ramana, O. Ramaré, *Quotients and Product Sets of Sets of Integers* (in preparation).

2. D.S. Ramana, O. Ramaré, *Exact Truncated Perron's Formula and Number of Primitive Roots in Short Intervals* (in preparation).

Visits to other Institutes:

1. University of Lille, Lille, France, November, 2014.

Invited Lectures/Seminars:

1. *Chromatic Sums of Squares*, University of Lille, Lille, November, 2014.

Other Activities:

1. Lectured in AFS I, Kumaun University, Almora, December 2014.

2. Lectured in the Refresher Course in Cryptography and Number Theory, Kerala School of Mathematics, Kozhikode, October, 2014.

3. G. Kasi Viswanadham submitted his thesis titled *Topics in Analytic Number Theory* to the HBNI under my supervision.

Raghavendra Nyshadham

Research Summary:

I have been working with one of my students on generalisations of the Atiyah-Weil theorem on holomorphic connections, and of the Krull-Remak-Schmidt theorem of Atiyah. I have also begun a project on homotopy type theory.

Visits to other Institutes:

1. Centre of Excellence in Mathematical Sciences, Kumaun University, Almora, 1-27 December, 2014.

Other Activities:

1. Gave a first-year course on Differential Manifolds from January to May, 2014.

2. Gave a second-year course on Algebraic Varieties from August to December, 2014.

3. Was the academic organiser of the Annual Foundational School I, 2014, of the National Centre of Mathematics, held at the Centre of Excellence in Mathematical Sciences, Kumaun University, Almora, from 1 to 27 December, 2014.

Ratnakumar Peetta Kandy

Research Summary:

My research in the last one year was mostly with my Ph. D students, Divyang Bhimani and Ramesh Manna. Work with Divyang concerns with study of wellposedness of Schrödinger equation on modulation spaces, which involves the study of action of nonlinearity on the modulation spaces, by composition. One of our main results is a characterization of nonlinearities that operates on the modulation space $M^{1,1}(\mathbb{R}^n)$. We have also shown that any nonlinearity that acts on $M^{p,1}(\mathbb{R}^n), p \geq 1$ by composition, has to be real analytic. This result, in particular answers an open question raised by Boaxiang et. al. regarding the action of non linearities of the form $F(u) = |u|^\alpha u$ on $M^{p,1}(\mathbb{R}^n)$ when α is not an even integer. An important consequence of our result is that the standard approach to study wellposedness in modulation spaces exploiting the algebra property, can be extended to handle, at most to real entire non linearities. In particular it throws light on the fact that the power type nonlinearity of the form $F(u) = |u|^\alpha u$, that is interesting from application point of view, requires new approach, when α is not an even integer. This work is completed and submitted for publication.

One of my work with Ramesh Manna concerns with maximal functions along hyper surfaces in $\mathbb{R}^{n+1}$. This refers to the maximal function obtained by averaging along a family of subsets in a hyper surface (analogous to balls in $\mathbb{R}^n$), and then taking the supremum of all averages. The interest in this maximal operator is that, though it arises from convolution with singular measures, it has much better L^p mapping properties unlike the spherical maximal operators and its generalization to other surface maximal operators. This work is completed and submitted for publication.

The other work with Ramesh involves, local smoothing estimates for fourier integral operators. We have made some progress towards obtaining sharp results regarding the local smoothing estimates for Fourier integral operators with phase function $\phi(x, \xi, t) = \langle x, \xi \rangle - t|\xi|$, which corresponds to the linear wave equation on $\mathbb{R}^n$. The study involves the wavefront set analysis and delicate oscillatory integral techniques and is still in progress.

Apart from this, the joint work with Vijay Kumar Sohani and Adimurthi on Hardy-Sobolev inequality for the twisted laplacian, started a couple of years ago has been completed recently, and submitted for publication.

Publications:

1. P. K. Ratnakumar, Vijay Kumar Sohani, *Non linear Schrödinger equation for the twisted Laplacian-Global wellposedness,* Mathematische Zeitschrift (to appear)

2. P. K. Ratnakumar. and Saurabh Kumar Shrivastava, *A remark on bilinear Littlewood-Paley square functions* Monatsh. Math. **176 , no. 4**, 615-622, (2015).

Preprints:

1. Divyang G. Bhimani, P. K. Ratnakumar *Functions operating on modulation spaces and nonlinear dispersive equations,* arXiv:1412.0362

2. Ramesh Manna, P.K. Ratnakumar, *Maximal functions along Hypersurfaces,* (Submitted for publication)

3. Adimurthi, P. K. Ratnakumar and Vijay Kumar Sohani , *A Hardy-Sobolev inequality for the twisted Laplacian,* (Submitted for publication)

Conference/Workshops Attended:

1. Organised jointly with K. Sandeep a *"Symposia in Harmonic Analysis and PDE"*, dedicated to the memory of S. Minakshisundaram on his birth centenary, in the 29th annual conference of the Ramanujan Mathematical Society, India, June 2014.

Visits to other Institutes:

1. Indian Institute of Science, Bangalore, March 2015.

2. TIFR CAM, Bangalore, January 2015.

3. Kerala School of Mathematics, Calicut, December 2014.

4. IISER, Pune, June 2014.

Invited Lectures/Seminars:

1. *Composition Operators on Modulation Spaces and Application to Schrödinger Equation*, Mathematics Seminar, Indian Institute of Science, Bangalore, March 2015.

Academic recognition/Awards:

- Nil

Other Activities:

1. Organised ”Symposia in Harmonic Analysis and PDE, dedicated to the memory of S. Minakshisundaram on his birth centenary”, in the 29th annual conference of the Ramanujan Mathematical Society, at IISER Pune (jointly with K. Sandeep), June 2014. other activities you have done, Month, year.

2. Reviwed the Ph. D. Thesis “Mixed norm estimates in Dunkl setting and chaotic behavior of heat semigroups” from Indian Institute of Science.

Gyan Prakash

Research Summary:

In a celebrated result of Ben Green, he showed that a dense subset of primes contains a non-trivial three term arithmetic progression. Then later he along with Terence Tao showed that a dense subset of primes contains a non-trivial arithmetic progression of any finite length. Later, they also proved that the set of primes contains any linear pattern of *finite complexity*. Recently there have been several efforts to obtain a quantitative version of their results. For example Helfgott and Roton proved that with A being any subset of $P(N)$, where $P(N)$ is the set of first N primes, with relative density $\delta_P A(N) := \frac{|A|}{|P(N)|} \geq c(\epsilon)\,(\log\log N)^{-1/3+\epsilon}$, the set A contains a non-trivial three term arithmetic progression.

In 2014, Kevin Henriot showed that for any system of translation invariant linear equations $Vx = 0$, with V having *complexity one*, any subset A of $P(N)$, where $P(N)$ is the set of first N primes, with relative density $\delta_P A(N) := \frac{|A|}{|P(N)|} \geq c(\epsilon)\,(\log\log N)^{-1/25t}$, where t is the number of variables in V, the set A contains a non trivial solution of V. In a joint work with K. Mallesham, we improved this result and also obtain a generalisation of it. In particular our result implies, that the exponent $-1/25t$ in the result of Henriot can be replaced by $-1/12t$ and also in place of $P(N)$, we may take the set of Chen primes. A prime p is said to be Chen prime, if $p+2$ has at most two prime factors.

Preprints:

1. K. Mallesham and Gyan prakash, *A generalisation of Roth's theorem in primes,* in preparation

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, May 2014,
2. Institute of Mathematical Sciencs, Chennai, India, February 2015.

Other Activities:

1. Taught Algebra II, during January-May 2015.

Ravindranathan Thangadurai

Research Summary:

Let a, b, c be given positive integers. Consider the Diophantine equation $ax^3 + by + c = xyz$. It is known that there are only finitely many tuples (x, y, z) such that x, y and z are positive integers and satisfy the diophantine equation. We obtained explicit bounds for individual x, y and z in terms of the given inputs a, b and c.
We observed that the well-known Ramanujan Tau function $\tau(n)$ is non-zero for all integers n such that if a prime $p|n$ and $p \not\equiv 39 \pmod{40}$. Also, we gave a new proof of the fact that if $\tau(n) = 0$ for some integer $n > 1$, then there exists a prime $p|n$ for which $\tau(p) = 0$.
The well-known conjecture in Transcendental Number Theory asserts that if x_1 and x_2 are two $\mathbf{Q}$-linearly independent complex numbers, and y_1 and y_2 are two $\mathbf{Q}$-linearly independent complex numbers, then one of the following four numbers

$$e^{x_1 y_1}, e^{x_1 y_2}, e^{x_2 y_1}, e^{x_2 y_2}$$

is transcendental. A serious study on this problem is currently under taken with some partial results in hand.

Publications:

1. R. Thangadurai and Pallab Kanti Dey, *The length of an arithmetic progression represented by a binary quadratic form*, Amer. Math. Monthly, **121** 932 - 936, (2014).

2. R. Thangadurai and S. Subburam, *On the Diophantine equation $x^3 + by + 1 - xyz = 0$*, C. R. Math. Acad. Sci. Soc. R. Can., **36**, 15-19 (2014).

3. R. Thangadurai and K. Viswanadham, *On the prime k-tuple conjecture*, Integers, **14** A28 (2014) 8pp.

4. R. Thangadurai and M. Ram Murty, *On the parity of the fourier coefficients of j-function*, Proc. Amer. Math. Soc. (Series A), **143**, 1391-1395 (2015).

Preprints:

1. R. Thangadurai and S. Subburam, *On the Diophantine equation* $ax^3 + by + c - xyz = 0$, To appear in: Functiones et Approximatio.

2. R. Thangadurai and S. Subburam, *On Erdős Wood's Conjecture*, To appear in: Proc. Indian. Acad. Sci. (series A).

3. R. Thangadurai, K. Senthil Kumar and M. Waldschmidt *Liouville sets and Liouville fields*, To appear in: Proc. Amer. Math. Soc. (Series A).

4. R. Thangadurai, A. Mukhopadyay and K. Viswanadham, *Unique representation of integers with base* A (in preparation).

5. R. Thangadurai and Balesh Kumar, *A note on Ramanujan's Tau function* (in preparation).

Conference/Workshops Attended:

1. AIS Combinatorics at HRI, Allahabad during 28 April to 17 May, 2014.

2. AFS - II at KSOM, Calicut during 21-28 May, 2014.

3. AIS Diophantine equations at Himachal University, Shimla during 16-21 June, 2014.

4. AIS Algebraic Number Theory at CMI, Chennai during 10-16 July, 2014.

5. ATMW on 'Topological Combinatorics' at HRI, Allahabad, during 06-11 October, 2014.

6. UGC-sponsored National Seminar on Number Theory and Combinatorics (NSNTC-14) at TKM College of Arts and Science, Kollam during 29-31 October 2014.

7. UGC refresher course at Savitribai Phule Pune University, Pune during 17-22, November, 2014.

8. Attended a workshop on "Modular forms" at University of Goa, Goa during 8-17, December, 2014.

9. A two days workshop in Number theory at National Academy of Sciences, India (NASI) during 22-23, December, 2014.

10. Number Theory Symposium at Indian Mathematical Society Conference held at Indian School of Mines (ISM), Dhanbad during 27-31, December, 2014.

11. Conference on ‘Analytic Number Theory” held at Tata Institute of Fundamental Research (TIFR), Mumbai during 5-9, January, 2015.

12. Workshop on “Modular Forms” held at KSOM, Calicut during 2-12, February, 2015.

Visits to other Institutes:

1. Kerala School of Mathematics, Calicut, May, 2014.
2. Himachal University, Shimla, June, 2014.
3. Chennai Mathematical Institute, Chennai, July, 2014.
4. TKM College of Arts and Science, Kollam, October, 2014.
5. Savitribai Phule Pune University, Pune, November, 2014.
6. University of Goa, Goa, December, 2014.
7. Indian School of Mines (ISM), Dhanbad, December, 2014.
8. Tata Institute of Fundamental Research, Mumbai, January, 2015.
9. Kerala School of Mathematics, Calicut, February, 2015.
10. Ramakrishna Mission Vidhyamandira, Belur, March, 2015.
11. Ramakrishna Mission Vivekananda University, Belur, March, 2015.

Invited Lectures/Seminars:

1. Delivered a course on “Zero-sum Problems” in AIS Combinatorics at HRI, Allahabad during 28 April to 17 May, 2014.

2. Delivered a course on “Semi-simple Modules and its structure” in AFS - II at KSOM, Calicut during 21-28 May, 2014.

3. Delivered a course on “Diophantine equations” in AIS Diophantine equations at Himachal University, Shimla during 16-21 June, 2014.

4. Delivered a course on "Abstract Integration" in Summer Programme in Mathematics at HRI, Allahabad during 26 June to 4th July, 2014.
5. Delivered a course on "Binary Quadratic forms, Gauss composition law" in AIS Algebraic Number Theory at CMI, Chennai during 10-16 July, 2014.
6. Delivered a course on "Topological dynamics and Diophantine inequalities" in ATMW on 'Topological Combinatorics at HRI, Allahabad, during 06-11 October, 2014.
7. Delivered two talks on "b-ary expansion of Real Numbers and Gauss Conjecture" in UGC-sponsored National Seminar on Number Theory and Combinatorics (NSNTC-14) at TKM College of Arts and Science, Kollam during 29-31 October 2014.
8. Delivered a course in 6 lectures on "Cebotarev Density Theorem" in UGC refresher course at Savitribai Phule Pune University, Pune during 17-22, November, 2014.
9. Attended a workshop on "Modular forms" at University of Goa, Goa during 8-17, December, 2014.
10. Delivered a lecture on "Prime Numbers" on a two days workshop in Number theory at National Academy of Sciences, India (NASI) during 22-23, December, 2014.
11. Delivered a lecture on "Schanuel's Conjecture" in the Number Theory Symposium at Indian Mathematical Society Conference held at Indian School of Mines (ISM), Dhanbad during 27-31, December, 2014.
12. Delivered a lecture on "Prime k-tuple Conjecture" in the conference on 'Analytic Number Theory" held at Tata Institute of Fundamental Research (TIFR), Mumbai during 5-9, January, 2015.
13. Delivered tour lectures on "$\zeta(3)$ is irrational" and three lectures in 'Modular forms' in a workshop on "Modular Forms" held at KSOM, Calicut during 2-12, February, 2015.
14. Delivered a colloquium talk on "Schanuel's Conjecture" at Ramakrishna Mission Vivekananda University, Belur on 11th March, 2015.

15. Delivered a general talk on “ Decimal Expansion of Real numbers and Artin’s Primitive root conjecture” at Ramakrishna Mission Vidhyamandira, Belur on 13th March, 2015.

16. Gave a short course (9 hours) on Quadratic fields at Ramakrishna Mission Vivekananda University, Belur during 7-16, March, 2015.

Academic recognition/Awards:

- EDUSHINE Award, 2014.

Other Activities:

1. Gave a second year advanced course on “Representation Theory” during August-December, 2014.

2. Conducted Summer Programme in Mathematics (SPIM 2014) at HRI in June, 2014.

3. Member of NBHM interview for MA/M.Sc scholarship and Ph. D fellowship.

4. Refereed papers in Journal of Number Theory, Integers, International Journal of Number Theory, Acta Arithmetica and Proceedings of Indian Academy of Sciences (Mathematical Sciences).

5. Member of the organizing committee of AIS Combinatorics, SPIM 2014, ATMW on Topological Combinatorics and Workshop on ‘Contact Topology’.

6. Dr. K. Senthil Kumar successfully defended his Ph. D thesis in November, 2014 at HRI under my guidance.

7. Convener of Transport Committee.

Manoj Kumar

Research Summary:

Let G be a finite group, n a multiple of $|G|$ and let $\mathcal{G}_n = \mathrm{Gal}(Q_n|Q)$ be the Galois group of the n-th cyclotomic extension. Then $\mathcal{G}_n$ acts on the set $Irr(G)$ as follows: for $\alpha \in \mathcal{G}_n$, $\chi \in Irr(G)$ and $g \in G$, we define

$$\chi^\alpha(g) = \chi(g)^\alpha \ ,$$

where $Irr(G)$ denotes the set of all irreducible characters of G. For $\chi, \psi \in Irr(G)$, if there exists a Galois automorphism $\alpha \in \mathcal{G}_n$ such that $\chi^\alpha = \psi$, then we say that χ and ψ are *Galois conjugate* (in $\mathcal{G}_n$). Characters in the same equivalence class have the degree.

In 1992, Berkovich, Chillag and Herzog classified the finite groups whose non-linear irreducible characters all have distinct degrees. We weaken this condition by asking that under the action of $\mathcal{G}_n$ there exists just one orbit on $Irr(G)$ of the irreducible characters for every given irreducible character degree $\neq 1$, and classify all finite groups satifying this weak condition. This classification includes abelian groups, p-groups with cyclic center and commutator subgroup of order p, some specific Frobenius groups and some simple groups.

Publications:

1. Pradeep K. Rai and Manoj K. Yadav, *On Ш-rigidity of groups of order p^6*, J. Algebra **428**, 26 - 42, (2015)

Preprints:

1. Silvio Dolfi and Manoj K. Yadav, *Finite groups whose non-linear irreducible characters of the same degree are Galois conjugate,* Submitted.

Conference/Workshops Attended:

1. *Discussion meeting on group theory*, IISER Mohali, May 2014.

2. *29th Annual conference of Ramanujan mathematical society*, IISER Pune, India, June 2014.

3. *International workshop "Knots, braids and automorphism groups"*, Novosobirsk, Russia, July 2014.

4. *International conference on algebra and its applications*, AMU Aligarh, India, December 2014.

Visits to other Institutes:

1. IISER Mohali, May - June 2014.

2. Sobolev institute of mathematics, Novosibirsk, Russia, July 2014.

3. IISER Pune, December 2014.

Invited Lectures/Seminars:

1. *Finite p-groups with maximum number of class-preserving automorphisms*, Discussion meeting on group theory, IISER, Mohali, May 2014.

2. *Class-preserving automorphisms and central quotients of finite p-groups*, 29th annual conference of RMS , IISER, Pune, June 2014.

3. *Finite p-groups with maximum number of class-preserving automorphisms*, International workshop on "Knots, braids and automorphism groups", Sobolew institute of mathematics, Novosibirsk, July 2014.

4. *Automorphisms of groups that preserve conjugacy classes*, Colloquium talk, IISER, Pune, December 2014.

5. *Finite p-groups with maximum number of class-preserving automorphisms*, International conference on algebra and its applications, AMU, Aligarh, December 2014.

Other Activities:

1. Examined one Ph. D. thesis and one M. Phil thesis for mathematics dept of AMU Aligarh, August - September 2014.

2. Refereed papers for many national and international journals.

3. Delivered three lectures on automorphisms of groups at Math. Dept., University of Patiala, Patiala as a part of RMS UGTE programme, June 2014.

4. Taught a week long course on isometries in AFS-I at CEMS Almora, December 2014.

5. Gave an advanced course on Combinatorial Group Theory at HRI, August - December 2014.

Hemangi Madhusudan Shah

Research Summary:

I worked extensively on harmonic, asymptotically harmonic spaces and pinching theorem for volume entropy from 1st May 2014 - 31st March 2015. The research summary is briefed as follows :

Harmonic Spaces:
1) Lichnerowicz Conjecture for dimension 6:
We are trying to prove that 6-dimensional harmonic manifold is either a flat or a ROSS (Rank One Symmetric Space). We are trying to generalise "standard basis" in dimension 5 to dimension 6.
2) Rank of harmonic manifolds :
Let (M,g) be a complete, simply connected and non-compact harmonic manifold. We are trying to show that geometric rank of M is one. For this we use ideas of Watkin's paper on rank rigidity theorem.

Asymptotically Harmonic Spaces:
1) Asymptotically harmonic spaces with minimal horospheres:
Recently, we showed that asymptotically harmonic manifold with minimal horospheres is flat, if it is Einstein. Now we are trying to prove flatness without the Einstein assumption.

Pinching Theorem for Volume Entropy:
We are about to complete the proof of following statement:
There exist a positive constant $\varepsilon(n, D)$ such that, if (M^n, g) is a compact Riemannian manifold of dimension $n \geq 3$ satisfying

- Ricci $(g) \geq -(n-1)g$,
- diam$(M, g) \leq D$,
- the volume entropy $h(g) \geq n - 1 - \varepsilon$, for some $\varepsilon \leq \varepsilon(n, D)$,

then

1) (M, g) carries a hyperbolic metric g_0,
2) $d_{GH}((M, g), (M, g_0)) \leq \alpha(\varepsilon)$, where $\alpha(\varepsilon)$ tends to 0 when ε tends to 0.

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.

Preprints:

(2) H. Shah, *On 3-dimensional asymptotically harmonic manifolds with minimal horospheres*, submitted for publication.

(3) G. Courtois and 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.

Satya Deo

Research Summary:

During this Academic Year 2014-15, I have been working on the research project on Topological Combinatorics under the Senior Scientist Fellowship of the National Academy of Sciences, India. The main emphasis has been to understand the topological colored version of the classical Tverberg theorem. I have now fully understood the remarkable formulation of the colored Tvreberg theorem given by Blagojevic, Matschke and Ziegler. The three proofs of their theorem given by them, using different ideas like the degree theory, obstruction theory and the G-index theory, are thoroughly clear to me. I have then given a motivational proof of the Reduction Lemma of BMZ theorem and formulated the statement of their theorem for maps to manifolds using the classical cohomological dimension theory. Collaborating with David Gauld of the University of Auckland, New Zealand, I have studied the finitistics spaces again. We have defined the star dimension of topological spaces with several interesting computational examples. Three publications have come out of these works which are listed in Publications.

The book writing project undertaken by Prof S.D. Adhikari and myself is still in progress. Some chapters of the proposed book on "Topological Combinatorics" have already been written and the remaining chapters are in preparation.

Publications:

1. Satya Deo, *Topological Colored Tverberg Theorem and the Reduction Lemma* , arXiv (Feb 2015)

2. Satya Deo and David Gauld, *Boundedly Metacompact or Finitistc Spaces and the Star Order of Covers,* J. Indian Math. Soc., to appear in (2015)

3. Satya Deo, *Colored Topological Tverberg Theorem of Blagojevic, Matschke and Ziegler,* Math Student, Accepted (2015).

Preprints:

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

Conference/Workshops Attended:

1. *Advanced Instructional School on Combinatorics at HRI, Allahabad*, India, April-May 2014.

2. *Advanced Foundational School on Differential Topology, Kerala School of Mathematics*, India, May 2014.

3. *Recent Advances in Analysis, YCCE, Nagpur*, India, July 2014.

4. *Keynote Address in the Conference on Special Functions and their Applications, T.D.College, Jaunpur*, India, Nov 2014.

5. *Keynote Address in the Inspire Programme of DST at SR College, Lucknow*, India, Nov 2014.

6. *Lecture at National Meet of Research Scholars in Maths and Stats, University of Jammu*, India, Dec 2014.

7. *Conference on National Mathematics Day, NASI, Allahabad*, India, Dec 2014.

8. *Annual Conference of Indian Math Soc., ISM, Dhanabad*, India, Dec 2014.

Visits to other Institutes:

1. DST PAC meeting at IISc, Bangalore, Feb 2014.

2. DST, PAC meeting at IIT, Chennai, June, 2014.

3. IMS Academic Programme Committee, University of Pune, Pune, July 2014.

4. DST, PAC committee meeting at IIT, Gandhinagar, Nov 2014.

5. APS University, Rewa, M.P., Nov 2014.

Invited Lectures/Seminars:

1. *On Birch-Tverberg theorem*, Invited lecture, International conference, YCCE, Nagpur, Jan 2014.

2. *Gave a course of 6 lectures on Topological Combinatorics*, Invited lectures, AIS at HRI, Allahabad, May 2014.

3. *Three Lectures on Differential Manifolds*, UGC Refresher Course, University of Allahabad, Allahabad, June 2014.

4. *Chief guest and keynote address*, INSPIRE programme of DST, SR College of Management and Technology, Lucknow, Nov 2014.

5. *Lecture on Polynomial Equations- Abel and Galois,* Invited lecture, APS University, Rewa, M.P., Nov 2014.

Academic recognition/Awards:

- Elected Chief Editor, J. Indian Math Society, for next three years
- Honourary Treasurer, National Academy of Sciences, India.

Other Activities:

1. Gave nine lectures on Simplicial Homology to the Students of HRI, Allahabad, Aug 2014.

2. Organized two-days workshop at the National Academy of Sciences, Allahabad to Celebrate the National Mathematics Day, Dec 22-23, 2014.

Jay Mehta

Research Summary:

A subset A of non zero Gaussian integers is said to be a *set of uniqueness* with respect to Gaussian integers if $f(A) = \{0\} \Rightarrow f \equiv 0$ holds for all completely additive functions $f : \mathbb{Z}[i]^* \to \mathbb{C}$.

In a joint work with G. K. Viswanadham, we proved that the set of Gaussian primes shifted by 1 is a set of uniqueness. As a consequence, we get that every non-zero Gaussian integer can be expressed as a finite product of rational powers of shifted Gaussian primes.

Publications:

1. Debika Banerjee and Jay Mehta, *Linearized product of two Riemann zeta functions*, Proc. Japan Acad. Ser. A Math. Sci. **90**, no. 8, 123-126, (2014).

2. Jay Mehta and G. K. Viswanadham, *Set of uniqueness of shifted Gaussian primes*, Funct. Approx. Comm. Math., To appear.

Preprints:

1. Jay Mehta, Biswajyoti Saha and G. K. Viswanadham, *An elementary approach to the meromorphic continuation of the multiple zeta functions*, (Preprint).

Invited Lectures/Seminars:

1. *A course in Cryptography*, Refresher course for college lecturers in Number Theory and Cryptography, Kerala School of Mathematics, Calicut, October 2014.

Akhilesh P.

Research Summary:

A chromatic version of Lagrange's Four Squares Theorem was obtained in joint work with D.S. Ramana. More precisely, we show that when the set of squares of the natural numbers is coloured with K colours, $K \geq 1$ an integer, the smallest integer $s(K)$ such that each sufficiently large integer can be written as the sum of no more than $s(K)$ squares, all of the same colour satisfies the bound $s(K) \ll_\epsilon K^{2+\epsilon}$, for any $\epsilon > 0$ and all $K \geq 1$. This improves on a result of N. Hegyvári and F. Hennecart, who had originally obtained $s(K) \ll (K \log K)^5$.

I participated in a research group guided by Prof. J. Oesterlé on computing Multiple Zeta Values. During the course of this activity, I wrote the Python programs for computing Multiple Zeta Values and their derivatives with very high accuracy. This allowed us, in particular, to check for linear relations among the computed values. Furthermore, we arrived at an algorithm for the fast computation of Multiple Zeta Values. This algorithm is based on a series expression for what we have called Double Tails of Multiple Zeta Values, which is obtained from the iterated integral expression for these values.

Publications:

1. *A chromatic version of Lagranges four squares theorem*, P. Akhilesh, D. S. Ramana, Monatshefte für Mathematik , January 2015, Volume 176, Issue 1, pp 17-29.

Preprints:

1. *Double tails of Multiple zeta values*,P.Akhilesh (in preparation)

2. *Higher derivatives of multiple zeta functions at integer points of the domain of convergence*, P. Akhilesh, J. Mehta, B. Saha, K. Senthil Kumar, G.K. Viswanadham (in preparation)

Conference/Workshops Attended:

1. *Sage Days 64* in University of California, Davis, 17-20 March 2015

2. *Sage Days 60* in IMSc Chennai, 14-17 August 2014

Visits to other Institutes:

1. Kerala School of Mathematics, Kozhikode, may 20 to june 2, 2014

Other Activities:

1. Tutorial Assitant in Annual Foundation Schools Part II - (2014),Kerala School Of Mathematics, Kozhikode, May 2014.

Kasi Viswanadham G

Research Summary:

A subset A of non-zero Gaussian integers is said to be a *set of uniqueness* if every complex valued completely multiplicative function on $\mathbf{Z}[i]^*$ that vanishes on A necessarily vanishes on all of $\mathbf{Z}[i]^*$. In a joint work with Jay Mehta, we proved that the set of shifted Gaussian primes is a set of uniqueness. As an application of this result we proved that every non-zero Gaussian integer can be written as a finite product of rational powers of shifted primes.

In a joint work with Jay Mehta and Biswajyoti Saha, we studied the analytic properties of the multiple zeta functions of depth $r \geq 1$. We proved that they have meromorphic continuation to $\mathbf{C}^r$. We also listed the exact poles of these functions together with the residues at these poles. We also extended our results to certain natural weighted variants of multiple zeta functions.

Publications:

1. Jay Mehta and G. K. Viswanadham, *Set of uniqueness of shifted Gaussian primes*, Funct. Approx. Comm. Math., To appear.
2. A. Mukhopadhyay, R. Thangadurai and G. K. Viswanadham, *Unique representation of integers with base A*, Arch. Math., To appear.

Preprints:

1. Jay Mehta, Biswajyoti Saha and G. K. Viswanadham, *An elementary approach to the meromorphic continuation of the multiple zeta functions*, Preprint.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, May 2014.

Invited Lectures/Seminars:

1. *Introduction to Number Theory*, Refresher course for college lecturers in Number Theory and Cryptography, Kerala School of Mathematics, Calicut, October 2014.

Pradeep Kumar Rai

Research Summary:

Let G be a group. An automorphism α of G is called class preserving if it maps each group element to some conjugate of itself. The set of all class-preserving automorphisms form a normal subgroup of $Aut(G)$, the group of all automorphisms of G. We denote this subgroup by $Aut^c(G)$. By $Out^c(G)$ we denote the factor group $Aut^c(G)/Inn(G)$, where $Inn(G)$ is the group of inner automorphisms of G. Let $Z_j(G)$, for $j \geq 0$, be the j-th term in the upper central series of G. In a recent work we have proved that if $Out^c(G/Z_j(G))$ is nilpotent of class k, then $Out^c(G)$ is nilpotent of class at most $j + k$. Moreover, if $Out^c(G/Z_j(G))$ is a trivial group, then $Out^c(G)$ is nilpotent of class at most j. As an application we prove that if $\gamma_i(G)/\gamma_i(G) \cap Z_j(G)$ is cyclic then $Out^c(G)$ is nilpotent of class at most $i + j$, where $\gamma_i(G)$, for $i \geq 1$, denotes the i-th term in the lower central series of G. This extends an earlier work of the author, where this assertion was proved for $j = 0$. We have also improved bound on the nilpotency class of $Out^c(G)$ for some classes of nilpotent groups G.

Let G be a group. An automorphism α of G is called a commuting automorphism if $[\alpha(x), x] = 1$ for all $x \in G$. Let $A(G)$ be the set of all commuting automorphisms of G. A group G is said to be an $A(G)$-group if $A(G)$ forms a subgroup of $Aut(G)$. In this work we give some sufficient conditions on a finite p-group G such that G is an $A(G)$-group. As an application we prove that a finite p-group G of coclass 2 for an odd prime p is an $A(G)$ group. Also we classify non-$A(G)$ groups G of order p^5.

Publications:

1. P. K. Rai and M. K. Yadav, *On Ш-rigidity of groups of order p^6*, J. Algebra **428**, 26-42, (2015).

2. P. K. Rai, *On commuting automorphisms of finite p-groups*, Proc. Japan Acad. Ser. A Math. Sci. **91**, 57-60, (2015).

Preprints:

1. P.K. Rai, *On nilpotency of group of outer class-preserving automorphisms of groups*, Accepted for publication in J. Algebra Appl.

Conference/Workshops Attended:

1. *Group Theory Workshop in memory of David Chillag*, Israel, October 2014.
2. *Discussion Meeting on Group Theory*, India, May 2014.
3. *Ischia Group Theory Conference* , Italy, April 2014.

Visits to other Institutes:

1. University of L'Aquila, L'Aquila, Italy, November 2014.

Invited Lectures/Seminars:

1. *On class-preserving automorphisms of a group*, Invited talk, University of L'Aquila, L'Aquila, November 2014.
2. *On class-preserving automorphisms of a group*, Contributed talk in the Discussion meeting, IISER Mohali, Mohali, May 2014.

Other Activities:

1. Presented a poster 'On Automorphisms of Groups" in Ischia Group Theory Conference, April, 2014.

Divyang G. Bhimani

Research Summary:

The Wiener amalgam and modulation spaces are of the importance of various applications of Harmonic analysis to PDEs. For a complex function F on $\mathbb{C}$, we study the associated composition operator $T_F(f) := F(f)$ on modulation spaces $M^{p,q}(\mathbb{R}^d)$ and Wiener amalgam spaces $W^{p,q}(\mathbb{R}^d)$ respectively in the following preprints. As an application, we have shown the standard method for the evolution of nonlinear dispersive (Shrödinger/wave/Klein-Gordon) equations cannot be considered for certain nonlinearity.
Finally, we have obtained some sufficient conditions for nonlinearity $fF(f)$ and $|f|$ to be in $M^{1,1}(\mathbb{R})$ whenever $f \in M^{1,1}(\mathbb{R})$ and F is a contraction on $\mathbb{C}$ in the following publication.

Publications:

1. D.G. Bhimani, *Contraction of functions in modulation spaces*, Integral Transforms Spec. Funct., http://dx.doi.org/10.1080/10652469.2015.1036055.

Preprints:

1. D.G. Bhimani and Ratnakumar P.K, *Functions operating on modulation spaces and nonlinear dispersive equations*, http://arxiv.org/abs/1412.0362.

2. D.G. Bhimani, *Composition operators on Wiener amalgam spaces*, arXiv:1503.01606.

Conference/Workshops Attended:

1. *ATM Workshop PDE and Fourier Analysis*, IIT- Kanpur, India, 8-20 December, 2014.

Eshita Mazumdar

Research Summary:

In my research work I mainly work on zero-sum problems. More precisely I studied the polynomial method to solve such problems. In my paper which has been accepted already we discussed about this polynomial method and we present some new results on some zero-sum constants obtained by generalizing a polynomial method. Moreover, let G be a finite abelian group (written additively), with exponent $\exp(G) = m$ and let A be a non-empty subset of $[1, m-1]$. The constant $\eta_A(G)$ (respectively $\mathsf{s}_A(G)$) is defined to be the smallest positive integer t such that any sequence of length t of elements of G contains a non-empty A-weighted zero-sum subsequence of length at most m (respectively, of length equal to m). These generalize the constants $\eta(G)$ and $\mathsf{s}(G)$, which correspond to the case $A = \{1\}$. In 2007, Gao et al.conjectured that $s(G) = \eta(G) + \exp(G) - 1$ for any finite abelian group G; we shall discuss a similar relation corresponding to the weight $A = \{1, -1\}$.

Publications:

1. Sukumar Das Adhikari, Eshita Mazumdar, B. K. Moriya, *Relation between two weighted zero-sum constants,* (submitted).

2. Sukumar Das Adhikari, Eshita Mazumdar, *The polynomial method in the study of zero-sum theorems,* accepted to "International Journal of Number Theory".

Talk

1. *Modification of a certain method in the study of a zero-sum constant*,The 12th annual workshop on Combinatorial and Additive Number Theory, CUNY Graduate Centre, New York, May 27-30,2014.

2. *On a modification of Griffiths method*, University of Minnesota, Mineapolis, June 5, 2014.

Tutorial

1. On the subject "Field Theory" in Summer Programme in Mathematics, HRI, June 16th- July 5th, 2014.

Conference/Workshops Attended:

1. *Discussion Meeting on Analytic Number Theory,* TIFR, India, January (5 - 9) 2015.

2. *ATM Workshop on Topological Combinatorics*, HRI, India, October (6-11) 2014.

3. *The 12th annual workshop on Combinatorial and Additive Number Theory*, at CUNY Graduate Centr, New York , May 27-30,2014.

Other Activities:

1. Working as a volunteer in a non-profitable organisation named ?Padakshep-US/UK? which is a public charity in wish to support meritorious highschool and undergraduate students in West Bengal, India, for whom pursuing higher education is a dream barred by their extreme economic hardship.
2. Stood 3rd in Three legged race which has been held HRI in 2015.
3. Stood 3rd in Badmintone tournament (doubles) which has been held HRI in 2015.

Ramesh Manna

Research Summary:

In the past one year, I have been studying the L^p boundedness for a class of maximal operators along hypersurfaces given by the graph of a function.

Let S be a hypersurfaces in $\mathbb{R}^{n+1}$ given by $x_{n+1} = h(x'),\ x' = (x_1, x_2, \cdots, x_n)$, where h is non negative C^1 function on $\mathbb{R}^n$. For $c \geq 0$, let $\Sigma_c = \{(x', x_{n+1}) \in S : 0 \leq x_{n+1} \leq c\}$ and for $f \in \mathcal{S}(\mathbb{R}^n)$, consider the average

$$A_c f(x) = \frac{1}{\mu(\Sigma_c)} \int\limits_{\Sigma_c} f(x-y)\, d\mu(y)$$

where μ denotes the surface measure on Σ_c induced by the Lebesgue measure. Define the corresponding maximal operator by

$$Mf(x) = \sup_{c>0} |A_c f(x)|.$$

Boundedness of this maximal operator on $L^p(\mathbb{R}^n)$ is being studied. In the proof we use a reduction to the dilated surface maximal operator, and a general version of Hardy-Littlewood maximal operator on $\mathbb{R}$, via a factorization of surface measure.

In the second work, 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.

Boundedness of this Fourier integral operators on L^p is being studied. The previous results was obtained by Christopher D. Sogge (1991). It was shown that, for $n = 2$ and $2 < p < \infty$ there is an $\epsilon(p) > 0$ so that

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

We are studying to get the above estimate when $p = \frac{2n}{n-1}$ with $\epsilon(p) = \frac{1}{p}$ and also in higher dimention. 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.

Preprints:

1. Ramesh Manna, P. K. Ratnakumar, *Maximal functions along Hypersurfaces,* (submitted for publication)

2. Ramesh Manna, P. K. Ratnakumar, *On Local Smoothing of Fourier Integral Operator*, (in preparation)

Conference/Workshops Attended:

1. *Compact Course on Navier-Stokes Equations for Incompressible Fluids*, TIFR-CAM Bangalore, India, 03 - 13 June, 2014.

2. *ATM Workshops on PDE and Fourier Analysis (2014)*, Indian Institute of Technology Kanpur, India, 8th to 20th Dec, 2014.

Other Activities:

1. Compiled HRI Annual Report for the academic year 2013-2014, May-July 2014.

SNEH BALA SINHA

Research Summary:

Harmonic numbers are defined as

$$H_n := \sum_{j=1}^{n} \frac{1}{j}$$

and its generalization is

$$H_{n,s} := \sum_{j=1}^{n} \frac{1}{j^s}, \quad n \in \mathbb{N}, s \in \mathbb{C}.$$

and define

$$H'_{2n-1,r} := \sum_{i=1}^{n} \frac{1}{(2i-1)^r}.$$

For any integer $k \geq 1$, Euler proved in 1734 that

$$\zeta(2k) = \frac{(-1)^{k-1} B_{2k} (2\pi)^{2k}}{2(2k)!}$$

where B_k is the k-th Bernoulli number given by the generating function

$$\frac{t}{e^t - 1} := \sum_{k=0}^{\infty} B_k \frac{t^k}{k!}.$$

These are the following results of the paper;

(1) For any positive integer k,

$$\sum_{i=1}^{\infty} \frac{\zeta(2k;i)}{i^{2k}} = \left\{ \left(\frac{B_{2k}}{2(2k)!} \right)^2 - \frac{B_{4k}}{2(4k)!} \right\} \frac{(2\pi)^{4k}}{2}.$$

(2) For any positve integer k, we have

$$\sum_{i=1}^{\infty} \frac{H_{i,2k}}{i^{2k}} \zeta(2k;i) = \left\{ (-1)^{3k-1} \frac{B_{6k}}{(6k)!} + (-1)^{3k-3} \frac{(B_{2k})^3}{8(2k)!^3} + (-1)^{3k-2} \frac{3B_{2k}B_{4k}}{4(2k)!(4k)!} \right\} \frac{(2\pi)^{6k}}{6}.$$

(3) For any positive integer k, we have

$$\sum_{i=1}^{\infty} \frac{\zeta(2k; i-1/2)}{(2i-1)^{2k}} = 2^{6k-2}\pi^{4k}\left[\frac{1}{2}\left(1-1/2^{2k}\right)^2 \frac{B_{2k}^2}{((2k)!)^2} - \left(1-1/2^{4k}\right)\frac{B_{4k}}{(4k)!}\right].$$

(4) For any positive integer k, we have

$$\begin{aligned}\sum_{n=1}^{\infty} \frac{H'_{2n-1,2k}}{(2n-1)^{2k}}\zeta(2k; n-1/2) = 2^{8k}\pi^{6k}\Bigg[&\frac{(-1)^k}{8}\left(1-1/2^{2k}\right)\left(1-1/2^{4k}\right)\frac{B_{2k}B_{4k}}{(2k)!(4k)!}\\ &+ \frac{(-1)^{3k-3}}{48}\left(1-1/2^{2k}\right)^3 \frac{B_{2k}^3}{(2k)!^3}\frac{(-1)^{3k-1}}{6}\\ &+ \frac{(-1)^{3k-1}}{6}\left(1-1/2^{6k}\right)\frac{B_{6k}}{(6k)!}\Bigg].\end{aligned}$$

Accepted, Czechoslovak Mathematical Journal

1. Sneh Bala Sinha and Jaban Meher, *Some infinite sum identities.*

Conference/Workshops Attended:

1. Dec 8 - Dec 16, 2014, Winter School in modular Form in one and several variables, at Goa university, Goa, India.
2. July 7 - 26 , 2014, AIS school on Algebraic Number Theory, at Chennai Mathematical Institute, Chennai, India.

Visits to other Institutes:

1. IMSc, Chennai, India during 27th July to 3 December 2014.

Tutorial:

1. Conducted tutorial for semester course in Topology at IMSc, Chennai.

Talk:

1. June 23, 2014 Transcendence of generalized Euler-Lehmer constants, Harish Chandra Research Institute, Allahabad, India.

Debika Banerjee

Research Summary:

Right now I am working on a new type of divisor problem with Prof. Makoto Minamide. In a paper Prof Makoto Minamide investigated the average of the coefficient of the Dirichlet series

$$\zeta'(s) = \sum_{n=1}^{\infty} D_1(n) n^{-s} \quad (Res > 1)$$

. He also obtained mean square of the error term $\triangle_1(x)$ of the asymptotic formula for $\sum_{n \le x} D_{(1)}(n)$. We are trying to get the first moment of $\triangle_{(1)}(x)$.

In a joint work with Prof. Makoto Minamide, We have shown that

$$\sum_{n \le x,\ p|n \Rightarrow p > y} (1 - \mu^2(n)) = O(x/\log^2 y)$$

with $x^{\varepsilon} < y \le x$. Here we shall consider the number of nonsquare-free positive integers $n \le x$ whose all prime factors are strictly bigger than y ('nonsquare-free' implies that the integer is divisible by at least a square of a prime number). To this end, we introduce a new kind of Buchstab's identity and using this identity we obtain an upper as well as a lower bound of the desired quantity. We further extended our result for general non k-free integers.

Preprints:

1. Debika Banerjee and Makoto Minamide, *A note on non square-free integers* (in preparation)

2. Debika Banerjee and Makoto Minamide, *A note on non k-free integers* (in preparation)

Conference/Workshops Attended:

Visit to Yamaguchi University: I visited from 24th July -10th August 2014. My visit was supported by Yamaguchi University.

Balesh Kumar

Research Summary:

In the past one year, I have been trying to understand the class number formulas of number fields. I have been trying to understand the class number of real quadratic number fields through a paper of Ankeny, Artin and Chowla. Also, I have been reading Hilbert modular forms and elliptic modular forms. Also, I am studing the properties of fourier coefficients of modular forms.

Preprints:

1. Balesh Kumar and Pallab Kanti Dey, *An analogue of Artin's primitive root conjecture*
2. Balesh Kumar and R. Thangadurai, *A note on Ramanujan's tau function* (in preparation)

Conference/Workshops Attended:

1. *Advanced instructional school on Diophantine equations*, India (Shimla), june,2014.
2. *Advanced instructional school on Algebraic number theory*, India (Chennai), july,2014.
3. *Winter School on Modular Functions in one and several variables*, India (Goa), December,2014.
4. *Workshop on Jacobi forms and modular forms of half integral weight*, India (Kozhikode), February,2015.
5. *International conference on automorphic forms and applications*, India (Kozhikode), February,2015.

Visits to other Institutes:

1. Kerala school of mathematics, Kozhikode, India, 18 December 2014 to 20 March 2015.

Other Activities:

1. Compiled HRI annual report for the year 2013-2014.

2. Tutor for the Advanced instructional school on Diophantine equations, India (Shimla), june,2014.

Pallab Kanti Dey

Research Summary:

I am working on Elliptic curves and Diophantine equations. Basically I am working on Elliptic curves over number fields. In this area I am trying to find out explicit torsion points in number fields for a given elliptic curve over number fields. Also I am trying to find out for a fixed torsion subgroup classification of elliptic curves. 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 change of sign in Fourier coefficients of modular form and arithmetic progression in cubes and squares over number fields.

Publications:

1. Pallab Kanti Dey and R.Thangadurai, *The length of an arithmetic progression represented by a binary quadratic form,* Amer. Math. Monthly **121**, 932-936, (2014).

Preprints:

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

2. Pallab Kanti Dey,*Torsion points over quadratic fields for a class of elliptic curves,* (submitted for publication).

Conference/Workshops Attended:

1. *Advanced Instructional Schools on Diophantine equations, June 16- July 04, 2014, HP University, Shimla, India.*

2. *Advanced Instructional Schools on Algebraic Number Theory, July 07- 26, 2014, CMI, Chennai, India.*

3. *Winter school on modular functions in one and several variables, December 08-17, 2014, Goa University, Goa, India.*

4. *Workshop on Jacobi Forms and Modular forms of half-integral weight, February 02-12, 2015, KSOM, Kerala, India.*

5. *International Conference on Automorphic forms and Applications, February 13-14, 2015, KSOM, Kerala, India.*

Other Activities:

1. Tutor for Advanced Instructional Schools on Diophantine equations, June 16- July 04, 2014, HP University, Shimla, India.

Mallesham.K

Research Summary:

Erdős and Szemerédi (1983) conjectured that for any finite subset of real numbers, one cannot have both its sumset and productset to be "*small*" simultaneously. In this direction, Elekes (1997) made progress by applying *Szemerédi-Trotter theorem* in the real plane. This theorem gives an upper bound for the number of incidences between given finite sets of lines and points in the real plane. Thus, the sum-product estimates and Szemerédi-Trotter theorem are intimately related. So, we have been looking for Szemerédi-Trotter type theorems in finite planes to improve sum-product estimates in finite fields.

Conference/Workshops Attended:

1. *AIS Algebraic number theory*, CMI, Chennai, July 2014
2. *ATMW Topological Combinatorics*, HRI, Allahabad, October 2014.

Rahul Kumar Singh

Research Summary:

During last one year I have been working on a problem which is about interpolating minimal surfaces between two given real analytic closed curves. We insert closed curves at specific locations and proved that there exists piecewise minimal surfaces of the Bjorling-Schwartz type which interpolates between the given two closed curves.This is joint work with my supervisor Dr. Rukmini Dey and Dr.Pradip Kumar.

I have also worked on a problem which gives the conditions such that Rotational, Helicoidal surfaces and Torus becomes locally bi-analytically equivalent to algebraic surfaces.This is joint work with my supervisor.

And I have also worked on a weak form of Isoperimetric inequality.We proved for complete simply connected surfaces of constant negative Gaussian curvature (hyperbolic surfaces) a weak form of isoperimetric inequality.This is joint work with Dr. Pradip kumar at Shiv Nadar University.

Conference/Workshops Attended:

1. *ATMW Preliminary workshop on Symplectic Geometry and Contact Topology (2014)*, HRI Allahabad, India, December, 2014.

2. *ATMW Advanced workshop and Discussion on Symplectic Geometry and Contact Topology (2014)*, TIFR Mumbai, India, December, 2014.

Bibekananda Maji

Research Summary:

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 $\Gamma = SL(2, \mathbb{Z})$.
I also working on finding the number fields generated by 4-torsion(and subsequently for n-torsion) points of an elliptic curve and the corresponding Galois groups using elementary group theory, class field theory and arithmetic of elliptic curve. Some cases have already been worked out.

In another work, I have written survey article on the infinitude of primes and provided a different proof of the same.

Recently I am trying to find rational points on elliptic curve such that they will form arithmetic progrssions.

Conference/Workshops Attended:

1. *AIS-Diophantine equation* at Himachal Pradesh University, India, June 16- July 4, 2014.

2. *AIS-Algebraic Number Theory* at Chenai Mathematical Institute, India, July 7 - 26, 2014.

Preprints:

1. B Maji, K. Chakraborty, S. Kanemitsu *Modular relations associated to the Rankin-Selberg L function*, communicated for publication.

2. B Maji, *On the infinitude of primes.*, communicated for publication.

3. B Maji, *Number Field generated by 4-torsion points of an elliptic curves, (in preparation).*

Other Activities:

1. I took tutorial in Advanced Instructional Schools on Diophantine equations, June 16- July 04, 2014, HP University, Shimla, India.
2. Solved problem no 11789, American Mathematical Monthly, Vol 121, No. 7 , Aug-Sep 2014.
3. With Soumyarup Banerjee, solved problem No 11802, American Mathematical Monthly, Vol 121, No. 8, Oct- 2014.
4. With Soumyarup Banerjee, solved problems in Mathematics Newsletter, Vol 24, March-June 2014.

Arvind Kumar

Research Summary

The space of modular forms of fixed weight on the full modular group has a basis of simultaneous eigenvectors for all Hecke operators. A natural question to ask is whether the product of two eigenforms (which may be of different weights) is an eigenform. The question was taken up by W. Duke [In Number theory in progress, Berlin (1999), 737-741] and E. Ghate [J. Ramanujan Math. Soc. 15 (2000), 71-79]. They proved that there are only finitely many cases where this phenomenon happens. Jaban Meher and Soumya Das [International Journal of Number Theory Vol. 11, No. 3 (2015) 835 - 842] considered the same problem in the space of quasi modular forms and found almost same kind of results. Then a more general question i.e., any finite product of eigenforms was studied by D. Lanphier and R. Takloo-Bighash [J. Ramanujan Math. Soc. 19 (2004), 253-259]. They also proved that except for finitely many cases, finite product of eigenforms is not an eigenform. Recently, Beyerl, James, Trentacoste, Xue [Ramanujan J. 27 (2012), 377-386] have proved that this phenomenon extends to a certain class of nearly holomorphic modular forms.
With J Meher, we establish a close relationship between quasi modular eigenforms and nearly holomorphic eigenfoms. We characterize all the cases in which products of finitely many nearly holomorphic eigenforms and products of finitely many quasimodular eigenforms for the full modular group are again eigenforms.
Apart from this I have been learning the theory of Jacobi Forms and Modular Forms of half integral weight.

Preprints:

1. Arvind Kumar and Jaban Meher, *On Arbitrary products of Eigenforms*, (in preparation)

Conference/Workshops Attended:

1. *AIS Algebraic Number Theory (2014)*, CMI Chennai, 7th to 26th July

2. *Winter School on modular functions in one and several variables (2014)*, Goa University, Goa, 8th to 17th October.

3. *Discussion Meeting on Analytic Number Theory (2015)*, TIFR, Mumbai, 5th to 9th January.

4. *Workshop on Jacobi forms and Modular forms of half-integral weight (2015)*, KSOM, Kozhikode, 2nd to 12th February.

5. *International Conference on Automorphic Forms and Applications, (2015)*, KSOM, Kozhikode, 13th and 14th February.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, June 2014

Other Activities:

1. Tutor in AFS- II, KSOM, Kozhikode, May 2014

Pramod Eyyunni

Research Summary:

I am studying topics in additive combinatorics. I had given my second year seminar talk on *"Characterizing additive sets with small doubling constant"* in June 2014. Continuing on from there, I then studied the *Balog-Szemerédi-Gowers Theorem* from which one can obtain a characterization of pairs of additive sets with large additive energy. I also studied other topics like *Roth's theorem* (for 3-term arithmetic progressions in integers) and the *sum-product* problem for fields, in general (*Freiman's theorem etc.*.) and for $\mathbb{R}$, in particular (results related to the *Erdős-Szemerédi conjecture*).

Conference/Workshops Attended:

1. *AIS Combinatorics*, HRI, Allahabad, April-May 2014,

2. *AIS Algebraic Number Theory*, CMI, Chennai, July 2014.

S.Manikandan

Research Summary:

My research area is Algebraic Geometry. I studied Krull-Schmidt theorem for an abelian category. This theorem says that any nonzero object has a unique direct sum decomposition into nonzero indecomposible object. I also studied its applications to the abelian category of coherent sheaves on complete algebraic variety over a field and also on compact complex manifolds. I am working on a problem related to a criterion due to Atiyah and Weil for a holomorphic vector bundle over a compact Riemann surface to admit a holomorphic connection.

Conference/Workshops Attended:

1. *AIS Schemes and Cohomology* , KSOM, Kozhikode, Kerala, December 1-19, 2014.

Bhuwanesh Rao Patil

Research Summary:

In the academic year 2014-15, I have studied about arithmetic progressions of arbitrary length in subsets of integers. Initially Erdős and Turán conjectured about the existence of 3 term arithmetic progressions in subsets of integers having positive density which was later proved by Roth. After that Szemerédi extended it by proving the existence of arithmetic progressions of arbitrary length in such sets. Among many proofs, I am trying to understand Furstenberg's proof which uses ergodic theory and also Gowers' proof which uses Fourier theory. I have also studied Balog-Szemerédi-Gowers theorem which characterizes pairs of sets with large additive energy and sum-product problem in $\mathbb{R}$, the proofs of which use probabilistic method and graph-theoretic notions.

Conference/Workshops Attended:

1. *AIS Combinatorics (2014)*, HRI Allahabad, 28th April-17th May
2. *ATMW Topological Combinatorics (2014)*, HRI Allahabad, 6th to 11th October.

Jitender Kumar

Research Summary:

In a broad outline, my research interests lie in the area of general algebra. Currently, I am working in the area of combinatorial semigroup theory. The study of rank properties of an algebraic structure provide some insight into the structure and its concrete description. The concept of rank for general algebras is analogous to the concept of dimension in linear algebra. However, for general algebras, in particular for semigroups, the minimum size of a generating set need not be equal to the maximum size of an independent set. Accordingly, for a finite semigroup S, Howie and Ribeiro have considered five possible ranks viz. small rank, lower rank, intermediate rank, upper rank and large rank of S.

We have studied all these ranks for the semigroup of endomorphisms over Brandt semigroups. Recently, in PhD thesis, I have introduced a technique to obtain the large rank of a finite semigroup. The problem of finding the large rank of a semigroup is still open for various semigroups. In a joint work with J. D. Mitchell, using the technique which relies on the concept of prime subsets, we have obtained the large ranks of $\mathcal{OD}_n, \mathcal{PODI}_n$ and $\mathcal{POD}_n$, the semigroups of singular selfmaps, injective partial and partial transformations on a finite chain $[n] = \{1, 2, \dots, n\}$, which preserve or reverse the order, respectively. Further, we have determined the large ranks of $\mathcal{POI}_n$ and $\mathcal{PO}_n$, the semigroup of injective order-preserving partial transformations and the semigroup of order-preserving partial transformations on $[n]$, respectively.

Preprints:

1. Jitender Kumar and J. D. Mitchell, *On the large rank of certain semigroups of transformations on a finite chain*, (in preparation)

2. Jitender Kumar, *Rank properties of the semigroup of endomorphisms over Brandt semigroups*, (in preparation)

Abhitosh Upadhyay

Research Summary:

After joining HRI, Allahabad, during July, 2014 to March, 2015, I studied lightlike hypersurfaces of indefinite cosymplectic manifold satisfying screen conformal condition. It has been proved that there exists no screen conformal
lightlike hypersurface M of an indefinite cosymplectic space form $\overline{M}(c)$ with $c \neq 0$. Also, conditions to write the hypersurface M as a product of the
distributions of tangent space and results including a characterization theorem have been obtained. Further, screen conformal Einstein ligtlike hypersurfaces of an indefinite cosymplectic space form has been introduced and condition for Ricci tensor of screen conformal lightlike hypersurfaces to be symmetric has been found. Examples of totally geodesic, screen
homothetic and screen conformal lightlike hypersurfaces have also been obtained.

Currently, I am working on two other problems:
1. The existence of Chaki-type pseudo symmetric lightlike hypersurfaces of Indefinite Complex and Indefinite Contact Manifolds
2. Gauss-Bonnet theorem for null surfaces

Preprints:

1. Abhitosh Upadhyay, Ram Shankar Gupta and A. Sharfuddin, *Screen Conformal Lightlike Hypersurfaces of Indefinite Cosymplectic Manifold,* (submitted)

Conference/Workshops Attended:

1. *Workshop on Symplectic Geometry and Topology*, HRI, Allahabad, India, 01-12 December, 2014

2. *Advanced School and Discussion Meeting on Symplectic and Contact Topology*, TIFR, Mumbai, India, 15-22 December, 2014

Makoto Sakagaito

Research Summary:

The Brauer group plays an important roll in number theory. For example the Brauer group is used to define the reciprocity map of local class field theory.

A few years ago, I defined a generalization of the Brauer group by using etale motivic cohomology. During the academic year 2014-2015, I considered problems whether the generalized Brauer group satisfies properties which the Brauer group satisfies. For example, I proved the exactness of the sequence for generalized Brauer groups which is an analogy of the Gersten conjecture for the Quillen K-theory in several cases. Furthermore, my research is in progress to generalize the Artin theorem for the Brauer group. This research relates to Hasse principle for Galois cohomology groups over function fields of curves that are defined over a Henselian discretely valued field.

Preprints:

1. Makoto Sakagaito, *On problems about a generalization of the Brauer group and Hasse principle* (in preparation)

Invited Lectures/Seminars:

1. *On problems about a generalization of the Brauer group*, Seminar, HRI, Allahabad, India, October 2014.

Vipul Kakkar, PDF Mathematics

Research Summary:

Transversals in groups are important as they determine the embeddings of subgroups in groups. Whenever we make our study of extensions of groups independent of transversals, we enter into obstructions and indeterminacies. This prompts us to study transversals individually and abstractally. Let H be a subgroup of a group G and S be a normalized right transversal (NRT) of H in G, that is the set S is obtained by selecting one and only one element from each right coset of H in G and $1 \in S$. Then S is a right loop with identity 1 with respect to operation $\circ$ on S defined by $\{x \circ y\} = Hxy \cap S$. Conversely, every right loop can be embedded as an NRT in a group with some universal property.

Let $\langle S \rangle$ be the subgroup of G generated by S and H_S be the subgroup $S \cap H$. Then $H_S = \{xy(x \circ y)^{-1} | x, y \in S\}$ and $H_S S = \langle S \rangle$. Identifying S with the set $H \backslash G$ of all right cosets of H in G, we get a transitive permutation representation $\chi_S : G \to Sym(S)$ defined by $\{\chi_S(g)(x)\} = Hxg \cap S$, $g \in G$, $x \in S$. The kernal of this action is $Core_G(H)$, the core of H in G. Let $G_S = \chi_S(H_S)$. Then $\chi_S(H_S S) = G_S S$.

During the academic year "2014-2015", we (jointly with Dr. Akhilesh Chandra Yadav, preprint available at http://arxiv.org/pdf/1501.00780.pdf) have described a key exchange protocol based on right transversals. We also describe it for general extension associated to right loops. Also, we (jointly with Dr. Vivek Kumar Jain, preprint avialable at http://arxiv.org/pdf/1505.07654.pdf) have obtained a necessary and sufficient condition for the normalizer of a core-free subgroup H of a finite group G to be normal in G. Also, a known result of finite groups is obtained through transversal.

Preprints:

1. Akilesh Chandra Yadav and Vipul Kakkar, *Public Key Exchange Using Right Transversals and Right Loops* http://arxiv.org/pdf/1501.00780.pdf

2. Vivek Kumar Jain and Vipul Kakkar, *A Study of Groups through Transversals* http://arxiv.org/pdf/1505.07654.pdf

Invited Lectures/Seminars:

1. I was one of the resource person in 5 day workshop on “Module Theory” organized by Central University of Kerrla, Kerala from Dec 15-19, 2014.

Other:

1. A book on axiomatic set theory is accepted for the publication in Narosa Publishing House, New Delhi.

Varun Dilip Thakre

Research Summary:

My research spans the areas of gauge theories and low-dimensional geometry. Currently, I am working on a generalization of the Seiberg-Witten equations in dimension four, which involves replacing the spinor representation - the space of quaternions $\mathbb{H}$ - by a *hyperKähler manifold* M with some additional symmetries. One can define a *non-linear* Dirac operator which can be additionally twisted by a connection on a principal G-bundle. This is used to define a generalization of the well-known Seiberg-Witten equations. I am currently working on constructing a suitable compactification of the moduli space of solutions to the generalized equations.

In [2], a dimensional reduction of the generalized Seiberg-Witten equations to two-dimensions has been studied. The reduction gives an additional Higgs field and "vortex-like" equations. When the Higgs-field vanishes, one obtains the familiar symplectic vortex equations. For the same, we have obtained regularity results and and are working on constructing a suitable compactification of the moduli space of solutions of the reduced equations. Aim is to define an analogue of the Gromov-Witten invariants for the hyperKähler manifold M.

Preprints:

1. Varun Thakre, *Regarding existence of Abelian theories admitiing apriori L^∞ bounds,* Unpublished work (2014)

2. Varun Thakre, *Dimensional Reduction of Generalized Seiberg-Witten equations,* (in revision) arXiv:1502.01486

Conference/Workshops Attended:

1. *Workshop on Symplectic Geometry and Contact Topology*, India, December 2014

2. *Advanced School and Discussion meeting on Symplectic Geometry and Contact Topology*, India, December 2014.

Shailesh Trivedi

Research Summary:

I have joined Harish-Chandra Research Institute, Allahabad on 13-02-2015. During the period February 13, 2015-March 31, 2015, I started to work on some problems which are summarized as follows.

The area of my research is concentrated on the study of various aspects of composition operators on different function spaces. Mathematically, let A be a non-empty set and $V(A)$ be a vector space of complex functions on A. If ϕ is a self-map on A, then ϕ induces a linear transformation C_ϕ from $V(A)$ to $V(A)$, defined as

$$C_\phi f = f \circ \phi \; for \; all \; f \in V(A).$$

If $V(A)$ is a Banach space and C_ϕ is bounded, we say that C_ϕ is a composition operator. During my Ph.D., I studied the local spectral theory of composition operators on l^p spaces, L^p spaces and the Disk Algebra. Now I have started working on the theory of the operators Cauchy dual to composition operators. Let C_ϕ be a left invertible composition operator on a Hilbert space H. Then the operator Cauchy dual to composition operator, C'_ϕ, is defined as $C'_\phi = C_\phi(C^*_\phi C_\phi)^{-1}$. The questions related to C'_ϕ which I am currently dealing with are as follows:

1. Does the decomposability of C_ϕ imply the decomposability of C'_ϕ and vice-versa?

2. If C_ϕ is completely hyperexpansive, then is C'_ϕ a subnormal contraction?

Conference/Workshops Attended:

1. *Conference on Geometry of Banach Spaces and Operator Theory, Department of Mathematics and Statistics, Indian Institute of Technology, Kanpur*, India, March, 2015.

Dipendu Maity

Research Summary:

A surface is a connected, compact 2-dimensional manifold. A map is a cellular embedding of a graph on a surface. A map in which faces are congruent of regular polygons and each vertex belongs to exactly same number of faces is called equivelar map and when two or more types of regular polygons meeting in identical vertices then it is called semi-equivelar map. Surfaces of Platonic solids are the examples of equivelar maps and Archimedean solids are the examples of semi-equivelar maps. There are eight types semi-equivelar maps exist on the torus and Klein bottle. These maps are studied and given their complete classification on the torus. Presently, we are working on this classification on the surface of Klein bottle.

Academic Report - Physics

J K Bhattacharjee

Research Summary:

During the last year my efforts have centred around a couple of issues in fluid turbulence. One of the central issues in the theory of turbulence is the issue of energy distribution over the different Fourier modes. For a wavenumber k (Fourier mode) , this energy distribution is denoted by $E(k)$ and called the energy spectrum. The sum over all possible values of k gives the total energy. In a statistically steady state of turbulence, Kolmogorov introduced a picture where the steady state is characterized by an equality between the rate at which energy is pumped into the system at observable (implying large) spatial scales (i.e. small values of k) and the rate at which this energy is dissipated at small spatial scales (i.e. large k) by molecular viscosity. In the intermediate range of k values which is far removed from scales at which energy is fed into the system and the scales at which the energy is dissipated in the fluid it was assumed that the properties of the turbulence would be universal. This range is known as the inertial range and is characterized by the scale k itself and the rate at which energy is transferred from one scale to another (same as dissipation or induction rate). Kolmogorov claimed that in the inertial range E(k) would be determined by k and the transfer rate and used a dimensional analysis to establish that E(k) is inversely proportional to the $5/3$ power of k. This is the Kolmogorov $-5/3$ law and has been reasonably well-established numerically and in real experiments. The above is valid for homogeneous isotropic turbulence. In a stratified fluid (e.g. atmosphere) a new complication arises because the total energy injected into the system at large spatial scales gives rise to two kinds of energy fluxes i.e transfer rates from large to small spatial scales. One is the kinetic energy and the other is the heat energy when the stratification is caused by an imposed thermal gradient. The scaling of the kinetic energy spectrum $E(k)$ will be determined by which flux will be dominant. Bolgiano and Obukhov argued that if the heat flux dominates then the spectrum will fall off as $11/5$ power instead of $5/3$. Inspite of extensive numerical and experimental efforts over the last two decades a clear crossover from $5/3$ to $11/5$ has never been seen. There could be two reasons for this failure to detect clear cut scaling and crossover in stratified fluid turbulence: i)the two exponents $5/3(= 1.67)$ and $11/5(= 2.2)$ are close enough to produce large overlap region which hides the true scaling behavior ii)it may not be clear under what circumstances the division of total energy flux between the kinetic energy flux and heat energy flux will end up favouring one over the other To handle the first issue we decided to explore the frequency spectrum .Repeating the scaling argument it was seen that if the kinetic energy flux dominated then the frequency spectrum would fall off as the inverse square power and if the heat flux dominated then the fall off would be as the fourth power. The difference in fall off being very different it allowed a clean demonstration of scaling and crossover in a numerical simulation. To explore the second issue we repeated the Kolmogorov argument for the stratified fluid and found that a definite statement about division of fluxes can only be made if the stratification is hydrodynamically stable and in that case the Richardson number determines the crossover from $5/3$ to $11/5$ spectrum. For very low Richardson numbers the exponent is $5/3$ and becomes $11/5$ as the number climbs to about unity.

Publications:

1. H S Samanta, J K Bhattacharjee, A Bhattacharyay and S Chakrabarty, *On noise induced Poincare-Andronov-Hopf bifurcation* Chaos 24 043122 (2014)

2. H Pharasi, K Kumar and J K Bhattacharjee, *Frequency spectra in turbulent thermal convection with rotation* Phys Rev E90 041004 (R)

3. J K Bhattacharjee , *Kolmogorov argument for the scaling of the energy spectrum in a stratified fluid* Phys Lett A379 696 (2015)

4. D Das, D Banerjee and J K Bhattacharjee , *Finding limit cycles in self-excited oscillators with infinite series damping functions* Europhys J D69 85 (2015)

Invited Lectures/Seminars:

1. *Introduction to fluid mechanics and turbulence* Set of lectures at the Bangalore statistical physics school 31st March 5th April 2014

2. *Science and Technology- a symbiotic relationship* Technology day lecture at NASI, Allahabad 11th May 2014

3. *Unusual Dynamics* Lecture at youth science meet at NASI, Allahabad September 2014

4. Scales and scaling in convective turbulence University of Hyderabad November 2014

5. Modelling of unusual dynamics Science enclave lecture at IIIT Allahabad 8th December 2014

6. Statistical mechanics of cold gases Set of lectures at IACS school on Cold matter and light interactions, December 2014

7. Scales and scaling in convective turbulence JNU 4th February 2015

8. Nonlinear Schroedinger equation and Gross Pitevski equation dynamics Set of lectures at BHU school on recent issues in quantum mechanics

9. Patterns in nature Science day lecture HRI 28th February

Other Activities:

1. Course at HRI integrated PhD program Classical Electrdynamics Aug- Dec (2014)

Anirban Basu

Research Summary:

I consider the D^6R^4 term which is the leading contribution in the low momentum expansion of the three loop, four graviton amplitude in maximal supergravity. I calculate the moduli dependent coefficient of this term in 11 dimensional supergravity compactified on T^2. Only diagrams that involve the Mercedes skeleton contribute resulting in a compact expression involving an integral over 6 Schwinger parameters. I express this integral as an integral over the moduli of an auxiliary T^3. This includes an $SL(3, Z)$ invariant integral over the shape moduli of the T^3. I discuss the renormalization of the ultraviolet divergences of this amplitude that arise from the boundaries of moduli space. The renormalized amplitude is simple which is a consequence of the fact that the D^6R^4 term is BPS.

The structure of one, two and three loop counterterms imposes strong constraints on several non–BPS interactions in the low momentum expansion of the three loop four graviton amplitude in maximal supergravity. The constraints are imposed by demanding consistency with string amplitudes. I analyze these constraints imposed on the D^8R^4 interaction in 11 dimensional supergravity compactified on T^2. I also discuss partial contributions from counterterms to interactions at higher orders in the momentum expansion.

Publications:

1. Anirban Basu, *Constraining non–BPS interactions from counterterms in three loop maximal supergravity,* Class.Quant.Grav. **32 (2015) 4, 045012**

2. Anirban Basu, *The D^6R^4 term from three loop maximal supergravity,* Class.Quant.Grav. **31 (2014) 24, 245002**

Conference/Workshops Attended:

1. *Current Themes in High Energy Physics and Cosmology*, Copenhagen, Denmark, August 2014,

2. *Indian Strings Meeting*, Puri, India, December 2014.

Visits to other Institutes:

1. Niles Bohr Institute, Copenhagen, Denmark, August 2014,
2. IIT Kharagpur, India, February 2015.

Invited Lectures/Seminars:

1. *The D^6R^4 term from three loop maximal supergravity* , Niles Bohr Institute, Copenhagen, Denmark, August 2014.
2. *Some Higher Derivative Corrections in String Theory* , IIT Kharagpur, February 2015.

Other Activities:

1. Tutor Main SERC School (course: Anomalies), BITS-Goa, January, 2015.

Tapas Kumar Das

Research Summary:

I have been working on accretion astrophysics, analogue gravity phenomena, astrophysics of our Galactic centre and on application of dynamical systems phenomena in large scale astrophysical fluid dynamics. One of our works on spectral signature of black hole spin has recently been highlighted in Nature.

Recently I have started looking into inter disciplinary problems like the simulation of horizon effects in low temperature condensed matter systems.

Publications:

1. Das, T. K., Nag, S., Hegde, S., Bhattacharya, S., Maity, I., Czerny, B., Barai, P., Wiita, P. J., Karas, V., & Naskar, T., *Black hole spin dependence of general relativistic multi-transonic accretion close to the horizon,* New Astronomy **37**, 81 – 104, (2015)

2. Ananda, D. B., Bhattacharya, S., & Das, T. K., *Acoustic geometry through perturbation of mass accretion rate - radial flow in static spacetimes,* General Relativity and Gravitation **To appear**, (2015)

3. Tarafdar, P., & Das, T. K., *Dependence of acoustic surface gravity on geometric configuration of axisymmetric background matter flow in the Schwarzschild metric,* International Journal of Modern Physics D **To appear** (2015)

4. Saha, S., Sen, S., Nag, S., Roychowdhury, S., & Das, T. K., *Model dependence of the multi-transonic behavior, stability properties and corresponding acoustic geometry for accretion onto a spinning black hole,* New Astronomy **To appear** (2015)

5. Ananda, D. B., Bhattacharya, S., & Das, T. K., *Emergent acoustic causality and stability analysis for axisymmetric flows through perturbation of mass accretion rate,* Classical & Quantum Gravity **Under review**, also at arXiv:1407.2268v3 [astro-ph.HE] (2014)

Invited Lectures/Seminars:

1. *Giant Black Holes in the Cosmos*, Keynote speech at Pantheon'14 – the annual academic and technological festival, Birla Institute of Technology, Mesra, Ranchi, India, September 2014.

2. *Astrophysical Black Holes*, Public Lecture, 'Astronomical Telescope Making' – workshop arranged by the Vigyan Prasar, New Delhi, Department of Science & Technology, Govt. of India, at the Jawahar Planetarium, , January, 2015.

3. *Black Hole Shadow Imaging*, Colloquium, at Presidency University, Kolkata, April 2015.

Other Activities:

1. Supervision of MS Thesis

   - Deepika B Ananda worked under my supervision for her thesis submitted towards partial fulfilment of BS-MS Dual Degree Programme of IISER Pune. The title of the thesis was *On metric independent perturbation scheme and associated relativistic acoustic geometry for spherical accretion*

2. Mentoring students

   (a) Shamreen Iram from IIT Kanpur.

   (b) Sanchari Pal from IIT Guwahati.

   (c) Sanhita Kabiraj from JNU.

   (d) Subhadeep Biswas from Hyderabad Central University.

   (e) Pranjal Pandey from IIT Roorkee (jointly with Dr. Saurav Bhattacharya, a former post doctoral fellow from the astrophysics group at HRI).

   (f) Ishika Palit from Bhopal University (jointly with Dr. Chiranjib Konar, a former post doctoral fellow from the astrophysics group at HRI).

   (g) Shefali Jayswal from Indian School of Mines, Dhanbad (jointly with Dr. Soumini Chaudhury, a post doctoral fellow from the astrophysics group at HRI).

(h) Hrishikesh Chakrabarty from Tejpur University (jointly with Satadal Datta, a Ph.D. student from the astrophysics group at HRI).

(i) Sowrabh Sudevan from Jain University (jointly with Deepika B Ananda, a project assistant from the astrophysics group at HRI).

3. Thesis Examination

   - Served as the examiner of a Ph.D. thesis on Plasma Physics and Magneto-hydrodynamics. Also conducted the viva voce for the thesis defense of the candidate (as external expert).

4. Teaching

   - Taught a one semester course (Astrophysics).

AseshKrishna Datta

Research Summary:

We have been studying the viability of two rather light (≤ 500 GeV) top squarks in the framework of the Next to Minimal Supersymmetric Standard Model (NMSSM) that keeps the hope of having 'natural Supersymmetry (SUSY)' alive. It is found that these are compatible with existing experimental bounds from the LHC, constraints on other low energy electroweak observable and those from the dark matter experiments. In a 'minimal' scenario proposed by us where these states (along with the lightest SUSY particle) are the only SUSY excitations within the reach of the LHC, the signals can be very different (in fact, rather indifferent when compared to generic SUSY signals for a compressed spectrum) from the conventional ones and thus can be missed at the LHC. Hence dedicated searches are called for. It is demonstrated that future LHC runs should be able shed light on such a spectrum. *This work is soon to be circulated.*

We perform a detailed study of the reported Higgs to diphoton rate at the LHC in the framework of $U(1)_R$-lepton number model with a right handed neutrino superfield. A large value of the corresponding neutrino Yukawa coupling f ($\sim \mathcal{O}(1)$) provides an additional tree level contribution to the lightest Higgs boson mass along with a very light (mass $\sim$ a few hundred MeV) bino like neutralino and a small tree level mass of one of the active neutrinos that is compatible with various experimental results. In the presence of this light neutralino, the total decay width of the Higgs boson and its various branching fractions are affected. When studied in conjunction with the recent LHC results, these put significant constraints on the parameter space. The signal rate obtained in this scenario is compatible with the recent results from both the LHC collaborations at 1σ level. A small value of 'f', on the other hand, is compatible with a sterile neutrino acting as a 7 keV dark matter that can explain the observation of a mono-energetic X-ray photon line by the XMM-Newton X-ray observatory. *This work has recently appeared in JHEP.*

The framework of minimal Universal Extra Dimension (mUED) has received much attention in recent times as it has been shown to have the potential to masquerade the SUSY signal at the LHC. The actual difference, however, lies in the details. Calculations of various key processes in the mUED and their implementations in some popular event generators are not adequate enough to address such details. In a collaboration with the peer group in University of Florida, USA we have been trying to address the core issue by improving over the currently available calculations and the implementations. *We are in the final stage of validating them rigorously.*

With my student and a past postdoctoral fellow at HRI, I have been engaged in the phenomenological study of an interesting possibility of two closely-lying (in mass) heavy vector bosons from the second Kaluza-Klein (KK) level in the framework of the nonminimal UED (nmUED). In sharp contrast to the mUED, the nmUED scenario has non-vanishing brane local parameters at the tree level which may give rise to large tree level couplings among such a KK gauge boson and the SM fermions. These could result not only in enhanced cross-sections for the Drell-Yan type production of a pair of leptons at the LHC via resonant KK gauge bosons but also could lead to large width for these resonant states thus opening up the possibility of a significant interplay of various related phenomena. Current LHC searches for similar heavy gauge bosons from different new physics scenarios are, in general, found to be sensitive to these nmUED excitations. However, the sensitivity is limited to the cases with the conventional assumption of relatively narrow widths for a lone resonant state. We demonstrate that the situation becomes highly involved when there is a pair of such close-by resonant states with moderate to large widths thus calling for a dedicated strategy in their hunt. *This work is nearing completion.*

Publications:

1. AseshKrishna Datta, Sabyasachi Chakraborty and Sourov Roy, *$h \to \gamma\gamma$ in $U(1)_R$-lepton number model with a right-handed neutrino* , JHEP **1502**, 124, (2015).

Preprints:

1. AseshKrishna Datta, Jyotiranjan Beuria, Arindam Chatterjee, Santosh Kumar Rai, *Two light stops in the NMSSM and the LHC,* (in preparation).

2. AseshKrishna Datta, Jyotiranjan Beuria, Dipsikha Debnath and Konstantin T. Matchev, *Production Cross Sections in the Minimal Universal Extra Dimension: The General Case of Non-degenerate Masses for Level-1 Kaluza-Klein Gluon and Quarks,* (in preparation).

3. AseshKrishna Datta, Kenji Nishiwaki and Saurabh Niyogi, *Broad resonances of the Nonminimal Universal Extra Dimension at the Large Hadron Collider* (in preparation).

Conference/Workshops Attended:

1. *MC4BSM-2014 (Workshop)*, South Korea, May, 2015.
2. *LHCDM-2015 (Workshop)*, India, February, 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. Invited to CERN, Geneva Switzerland for an academic visit during summer 2015.

Invited Lectures/Seminars:

1. Invited seminar on *Status of UED simulations*, MC4BSM-2014, Center for Theoretical Physics of the Universe, Daejeon, South Korea, May, 2015.

Academic recognition/Awards:

None

Other Activities:

1. Served in the International Organizing Committee of the workshop MC4BSM-2014 (Monte Carlo Tools for Physics Beyond the Standard Model) held in Daejeon, South Korea in May, 2014.
2. One student submitted his Ph.D. thesis under my supervision in September, 2014.
3. Supervising one student towards his Ph.D. degree (since December, 2013).
4. Serving the Doctoral Committee of 6-7 students.
5. Offered a semester-long reading course to three students (fall, 2014; credited) and a half a semester long informal project to one student (summer, 2014; not credited).
6. Served as the referee for international journals.

7. 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:

In the year 2014-15, we have studied the effects of decoherence or defects on quantum correlations in different physical systems. One of the difficulties encountered in realizations of quantum information protocols is that quantum correlations decohere rapidly by interaction with the environment. On the other hand, generation of entanglement in composite systems, requires interaction between its subsystems and hence strongly interacting systems, such as quantum spin chains, form natural resources of entanglement. However, imperfection and impurities come naturally in several physical systems including ultracold atoms, nitrogen-vacancy centers in diamonds, solid-state systems, and ion traps. Hence disordered systems form one of the centerstages of studies in many-body physics.

In a work, we have shown that in ordered spin systems, the twin restrictions of translation invariance and monogamy of quantum correlations, in general, enforce the bipartite states to be neither Bell inequality violating nor dense-codeable. In contrast, we have found that these quantum characteristics, viz. Bell inequality violation and dense-codeability, can be resurrected, and thereby the no-go theorems overcome, by having quenched disorder in the system parameters leading to quantum spin glass or quantum random field models.

Although a few studies have addressed the issue of preserving quantum correlation measures during their dynamics, identifying the inherent property in quantum states, prohibiting the loss of quantum correlations over time, is still an open question. In a work, we derive necessary and sufficient conditions for freezing of quantum correlation measures, for both quantum discord and quantum work deficit, when a two-qubit state with magnetization is subjected to local depolarizing channels, in which bitflip, phaseflip, or bit-phase-flip errors can occur. For states which do not exhibit freezing properties, but can be frozen effectively by suitable tuning of the state parameters, we introduce an index "the freezing index" to quantify the goodness of freezing. We find that the freezing index can be used to detect quantum phase transitions and discuss the corresponding scaling behavior.

It has been shown, both theoretically as well as experimentally, that bipartite entanglement is an essential ingredient for a vast majority of known quantum communication schemes, involving two parties. Unlike point to point communication, where among two parties, one acts as a sender and the other as a receiver, communication protocols involving multiple parties can have various complexities. In a work, we establish a relation between the capacity of multipartite dense coding and multipartite quantum correlation measures of arbitrary multiqubit states. Such investigations have been carried out both in noiseless and noisy scenarios.

In another work, we have investigated the behavior of genuine multiparticle entanglement, as quantified by the generalized geometric measure, in gapless-to-gapped quantum transitions of one- and two-dimensional quantum spin models. We have found that the multipartite quantum correlation measure are better indicator of quantum critical points than the bipartite measures, especially for two-dimensional models.

Publications:

1. T. Das, R. Prabhu, A. Sen(De), and U. Sen, *Multipartite Dense Coding vs. Quantum Correlation: Noise Inverts Relative Capability of Information Transfer,* Phys. Rev. A **90**, 022319 (2014)

2. A. D. Rane, U. Mishra, A. Biswas, A. Sen(De), and U. Sen, *Benford's law gives better scale exponents in phase transitions of quantum XY models,* Phys. Rev. E **90**, 022144 (2014)

3. A. Biswas, R. Prabhu, A. Sen(De) and U. Sen, *Genuine multipartite entanglement trends in gapless-to-gapped transitions of quantum spin systems,* Phys. Rev. A **90**, 032301 (2014)

4. Salini K., R. Prabhu, A. Sen(De), and U. Sen, *Monotonically increasing functions of any quantum correlation can make all multiparty states monogamous,* Ann. Phys. **348**, 297 (2014)

5. A. Bera, D. Rakshit, M. Lewenstein, A.Sen(De), U. Sen, and J. Wehr, *Classical spin models with broken symmetry: Random Field Induced Order and Persistence of spontaneous magnetization in presence of a random field,* Phys. Rev. B **90**, 174408 (2014)

6. U. Mishra, A. Sen(De), and U. Sen, *Local Decoherence-free Macroscopic Quantum states,* Phys. Lett. A **379**, 261 (2015)

7. A. Kumar, R. Prabhu, A. Sen(De), and U. Sen, *Do Large Number of Parties Enforce Monogamy in All Quantum Correlations?,* Phys. Rev. A **91**, 012341 (2015)

8. D. Sadhukhan, S. Singha 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).

9. A. Misra, A. Biswas, A.K. Pati, A. Sen(De), and U. Sen, *Quantum Correlation with Sandwiched Relative Entropies*, Phys. Rev. E (in print) (2015)

Preprints:

1. U. Mishra, D. Rakshit, R. Prabhu, A. Sen(De), and U. Sen, *Constructive Interference Between Disordered Couplings Enhances Multiparty Entanglement in Quantum Heisenberg Spin Glass Models,* arXiv:1408.0179

2. T. Chanda, A.K. Pal, A. Biswas, A. Sen(De), and U. Sen, *To freeze or not to: Quantum correlations under local decoherence,* . arXiv:1409.2096

3. T. Das, A. Kumar, A.K. Pal, N. Shukla, A. Sen(De), and U. Sen, *Canonical Distillation of Entanglement,* arXiv:1411.7936

4. T. Das, R. Prabhu, A. Sen(De), and U. Sen, *Distributed quantum dense coding with two receivers in noisy environments,* arXiv:1412.6247

5. T. Chanda, U. Mishra, A. Sen(De), and U. Sen, *Time dynamics of multiparty quantum correlations indicate energy transfer route in light-harvesting complexes,* arXiv:1412.6519

6. D. Sadhukhan, R. Prabhu, A. Sen(De), and U. Sen, *Thermal Fluctuations Enhance Order-from- Disorder of Quantum Correlations in Quenched Disordered Spin Models,* arXiv:1412.8385

7. H. S. Dhar, D. Rakshit, A. Sen(De), and U. Sen, *Adiabatic freezing of long-range quantum correlations in spin chains,* arXiv:1502.01489

8. D. Sadhukhan, S. Singha Roy, D. Rakshit, R. Prabhu, A. Sen(De), and U. Sen, *Enhancement of Quantum Correlation Length in Quenched Disordered Spin Chains,* arXiv:1503.04770

Conference/Workshops Attended:

1. *"Young Quantum - 2015 (YouQu-2015)" at HRI*, India, February 2015.

Visits to other Institutes:

1. Theoretical Physics Unit, Tata Institute of Fundamental Research, Mumbai, India, April 2014
2. Raman Resaerch Institute, Bangalore, India, September 2014
3. Jawaharlal Nehru University, New Delhi, India, February 2015
4. Indian Association for the Cultivation of Science, Kolkata, India, March 2015

Invited Lectures/Seminars:

1. *Monogamy of Quantum Correlations*, Theoretical Physics Seminar, Tata Institute of Fundamental Research, Mumbai, India, April 2014.
2. *Benford's law detects quantum phase transitions*, Indian Association for the Cultivation of Science , Kolkata, India, March 2015.

Other Activities:

1. Taught a one-semester course on "Classical mechanics" during Aug-Dec 2014.
2. Guiding the theses of Tamoghna Das, Debasis Sadhukhan, Titas Chanda of HRI and Himadri S Dhar from JNU.
3. Guided projects of the following HRI graduate students:
   (a) Debasis Sadhukhan on " Entanglement Length in Disordered Model" (Big project: Jan-May 2014)
   (b) Tamoghna Das, on "Quantum Communication Network" (Big project: Jan-May 2014).
   (c) Titas Chanda, on "Freezing phenomena of Quantum Correlations" (Jan-May 2014).
   (d) Titas Chanda on "Dynamics of Quantum Correlations under Decoherence" (Big project: "Aug-Dec 2014).
   (e) Chiranjib Mukhopadhyay "Monogamy of quantum correlations" (Aug-Dec 2014).
   (f) Saptarshi Roy "Role of entropy in Quantum Information" (Jan-MAy 2015).

4. Served as member of the advisory committee of a meeting on "Young Quantum - 2015 (YouQu-2015)" held at HRI in February 2015.

5. Guiding the project work of a student, K Sriram, Indian Institute of Science Education and Resaerch, Pune, May-July 2014.

6. Serving as the convenor of the Housing Committee,Office Allocation and Furnishing, and member of the Pantry, 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,.

Raj Gandhi

Research Summary:

My work over the past year has focussed on dark matter, ultra-high energy neutrinos, long baseline physics, and precision measurements of particle physics which can be done by a near neutrino detector. With my student Aritra Gupta and former student Atri Bhattacharya, we proposed detection of relativistic dark matter (DM) in large detectors like IceCube. The bulk of DM must be massive and non-relativistic, but if it slowly decays (with lifetimes greater than the age of the Universe) into another DM particle which is much less massive, then a small relativistic component of DM would be produced, whose interactions would look like neutral current neutrino events in a large neutrino detector. This was studied in JCAP 1503 (2015) 03, 027 , and further work is ongoing.

Several experiments point towards the possible presence of one or more species of sterile neutrinos. WIth Boris Kayser, my student Mehedi Masud and Suprabh Prakash (HRI postdoctoral fellow), we have studied the effects of sterile states on CP violation measurements currently planned by long baseline experiments like DUNE (Deep Underground Neutrino Experiment) . We find that these effects significantly impact planned measurements, and may compromise their planned sensitivities appreciably.

Other work includes the physics capabilities of capabilities of DUNE (arXiv:1405.1054), probes of CPT and Lorentz violation (JHEP 1406 (2014) 045) and non-standard interactions in atmospheric neutrinos (arXiv:1409.8472).

Publications:

1. Atri Bhattacharya (Arizona U.), Raj Gandhi (Harish-Chandra Res. Inst. and Fermilab), Aritra Gupta (Harish-Chandra Res. Inst.), *The Direct Detection of Boosted Dark Matter at High Energies and PeV events at IceCube* JCAP 1503 (2015) 03, 027

2. Animesh Chatterjee (Harish-Chandra Res. Inst.), K.K. Meghna (IMSc, Chennai), Kanishka Rawat (Panjab U., Chandigarh), Tarak Thakore (Tata Inst.), Vipin Bhatnagar (Panjab U., Chandigarh), R. Gandhi (Harish-Chandra Res. Inst.), D. Indumathi (IMSc, Chennai), N.K. Mondal (Tata Inst.), Nita Sinha (IMSc, Chennai), *A Simulations Study of the Muon Response of the Iron Calorimeter Detector at the India-based Neutrino Observatory* JINST 9 (2014) P07001

3. Animesh Chatterjee, Raj Gandhi (Harish-Chandra Res. Inst.), Jyotsna Singh (Lucknow U.), *Probing Lorentz and CPT Violation in a Magnetized Iron Detector using Atmospheric Neutrinos*, JHEP 1406 (2014) 045

4. Kalpana Bora (ed.) (Gauhati U.), D.P. Roy (ed.), Raj Gandhi (ed.), Dilip Kumar Chodhury (ed.), N. Nimai Singh (ed.), Nita Sinha (ed.), Madhurjya P. Bora (ed.), Anjan Ananda Sen *Proceedings, National Conference on Contemporary Issues in High Energy Physics and Cosmology*, J.Phys.Conf.Ser. 481 (2014)

Preprints:

1. Vernon Barger (Wisconsin U., Madison), Atri Bhattacharya (Arizona U.), Animesh Chatterjee, Raj Gandhi (Harish-Chandra Res. Inst.), Danny Marfatia (Hawaii U.), Mehedi Masud (Harish-Chandra Res. Inst.) *Configurations of the Long-Baseline Neutrino Experiment*, arXiv:1405.1054

2. (Shakeel Ahmed (Aligarh Muslim U.) et al.), *Physics Potential of the ICAL detector at the India-based Neutrino Observatory (INO) ICAL Collaboration* , arXiv:1505.07380

3. Animesh Chatterjee (Harish-Chandra Res. Inst.), Poonam Mehta (Nehru U.), Debajyoti Choudhury (Delhi U.), Raj Gandhi (Fermilab and Harish-Chandra Res. Inst.), *Testing non-standard neutrino matter interactions in atmospheric neutrino propagation* , arXiv:1409.8472.

Conference/Workshops Attended:

1. *Neutrinos: Recent Developments and Future Challenges*, Kavli Institute for Theoretical Physics, USA, November 2014.

2. *"Workshop on the Near Neutrino Detector* , Fermilab, USA, July , 2014.

3. *XXI DAE-BRNS High Energy Physics Symposium, 2014*, IIT- Guwahati, India, December 2014, .

Visits to other Institutes:

1. Fermilab, Chicago, USA, June and July 2014 ,

2. Fermilab, Chicago, USA, September-November 2014.

3. Kavli Institute for Theoretical Physics, Santa Barbara, USA, October 2014

Invited Lectures/Seminars:

1. Plenary talk on *The Highest Energy Neutrinos* at the XXI DAE-BRNS High Energy Physics Symposium, 2014, IIT- Guwahati.
2. Plenary talk on *Long Baseline Neutrinos: Physics and Status* at the XXI DAE-BRNS High Energy Physics Symposium, 2014, IIT- Guwahati.
3. Invited Talk at the conference Neutrinos: Recent Developments and Future Challenges, on *LBNE :Physics and Status*, on Nov 7, 2014, KITP, Santa Barbara.
4. Invited Talk at the Workshop on the Near Neutrino Detector on *Physics Issues related to the near Detector*, on July 29, 2014, Fermilab.
5. High Energy/Cosmology Theory Seminar on *"Ultra-High Energy events and Dark matter"* 2 October 2014 at UW Madison.
6. Physics Colloquium," *Ultra-High Energy Neutrinos"* JNU, Delhi, Dec 2014.

Academic recognition/Awards:

- Fermilab Intensity Frontier Fellow, 2014.

Other Activities:

1. I am currently guiding 3 PhD students, Mehedi Masud, Aritra Gupta and Sandeep Sherawat.
2. In Spring 2015, I supervised 7 HRI students for their semester long projects (Khorsed Alam, Sandeep Sherawat, Dipyaman Pramanik, Samiran Roy, Gautam Sharma, Shouvik Roychoudhury and Sarif Khan)
3. Physics Co-ordinator Indian Institutions Fermilab Collaboration for Deep Underground Neutrino Experiment, 2013 to present.
4. Member, Deep Underground Neutrino Experiment, (DUNE) USA.

Rajesh Gopakumar

Research Summary:

In the last year, my research on higher spin theories and their holographic duals has come closer to string theory. I have been trying to use our understanding of such higher spin holographic duals to learn how they are embeddded in string theory. One of the broad aims is to see how the higher spin symmetries fit into the larger symmetries of string theory and how these can constrain the structure of string theory itself.

With Matthias Gaberdiel, we focussed on string theory on the background $AdS_3 \times S^3 \times T^4$. We were able to identify a Vasiliev higher spin subsector of the above AdS string theory. Moreover, this also enabled us to reorganise the full partition function of the dual symmetric product CFT in terms of representations of the higher spin algebra (or rather its W_∞ extension). In particular, the unbroken stringy symmetries of the tensionless limit, as reflected in the extended chiral algebra of the symmetric product CFT, can be characterised by nontrivial W_∞ representations which vastly extend the conventional higher spin symmetry. We then went onto understand these stringy symmetries in more detail. We uncovered a novel structure of a higher spin square in which the whole stringy symmetry algebra was generated by two different higher spin algebras. We are trying to understand this structure better and see the constraints it imposes on the spectrum of the theory away from the symmetry unbroken point.

In a different line of development, together with Arnab Rudra, Sourav Sarkar and Mrtitunjay Verma we have been exploring properties of perturbative CFTs in Mellin space. The mellin representation of Feynman amplitudes in a conformal field theory has properties analogous to the momentum space representation in ordinary QFT amplitudes. Properties such as factorisation of amplitudes into different channels with poles representing exchanged operators are manifest in mellin space. The idea is to therefore use this representation for implementing gauge string duality for CFTs preserving all the conformal symmetries. To do this, we have therefore been attempting to identify Feynman rules for Mellin amplitudes in a perturbative CFT. So far this has been successful for an arbitrary tree diagram in which one can assign propagators to every edge of the tree. We plan to see how to generalise this to loops.

Publications:

1. M. R. Gaberdiel and R. Gopakumar, *Higher Spins and Strings*, JHEP **1411**, 044 (2014).

2. M. R. Gaberdiel and R. Gopakumar, *Stringy Symmetries and the Higher Spin Square*, J. Phys. A (To Appear) (2015)

Preprints:

1. R. Gopakumar, A. Rudra, S. Sarkar, M. Verma *Mellin Space Feynman Rules* In Preparation

Conference/Workshops Attended:

1. *Strings 2014*, Princeton University, USA, Jun. 2014.

2. *Amsterdam Workshop on String Theory*, University of Amsterdam, Netherlands, Jul. 2014.

3. *Recent Developments in String Theory*, Centro Stefano Franscini, Ascona, Switzerland, Jul. 2014.

4. *Indo-UK Frontiers of Science*, Khandala, India, Oct. 2014.

5. *TWAS General Body Meeting*, Muscat, Oman, Oct. 2014.

6. *Indian Mathematical Society Annual Meeting*, ISM, Dhanbad, India, Dec. 2014.

7. *Discussion Meeting on String Theory*, ICTS-TIFR, Bangalore, Feb. 2015.

8. *ICTP Spring School on Superstring Theory*, ASICTP, Trieste, Italy, Mar. 2015.

Visits to other Institutes:

1. Weizmann Institute, Rehovot, Israel, May 2014.

2. Ben-Gurion Universiy, Beersheba, Israel, May 2014.

3. ICTS-TIFR, Bengaluru, India, Jun. 2014, Sept. 2014, Nov. 2014. Jan. 2015, Feb. 2015.

4. TIFR-Mumbai, Jun. 2014.

5. University of Amsterdam, Amsterdam, The Netherlands, Jul. 2014.
6. ETH-Zurich, Zurich, Switzerland, Jul. 2014.
7. IIT-Kanpur, Kanpur, India, Nov. 2014.
8. Abdus Salam ICTP, Trieste, Mar. 2015.

Invited Lectures/Seminars:

1. *From Higher Spins to Strings*, Neve Shalom Seminar, Israeli Joint Institutes, Neve Shalom, May 2014.
2. *Open-Closed-Open Triality*, Group Seminar, Weizmann Institute, Rehovot, Israel, May 2014.
3. *From Higher Spins to Strings*, String Seminar, ICTS-TIFR, Bengaluru, Jun. 2014.
4. *From Higher Spins to Strings*,DTP Seminar, TIFR-Mumbai, Mumbai, Jun. 2014.
5. *From Higher Spins to Strings*, Plenary Talk, Strings 2014, Princeton, USA, Jun. 2014.
6. *From Higher Spins to Strings*, Amsterdam Workshop Seminar. Amsterdam. Jul. 2014.
7. *From Higher Spins to Strings*, Ascona Workshop Invited Talk, Ascona, Jul. 2014.
8. *Stringy Symmetries*, ICTS Seminar, Bangalore, India, Sept. 2014.
9. *Simplifying String Theory*, TWAS Prize Lecture, Muscat, Oman, Oct. 2014.
10. *Simplifying String Theory*, HRI Felicitation, Allahabad, India, Oct. 2014.
11. *The Remarriage of Mathematics and Physics*, Maths Colloquium, IIT-Kanpur, India, Nov. 2014.
12. *A Physics Perspective on Gromov-Witten Theory (2 lecs.)*, Workshop on Symplectic Topology, HRI, Allahabad, Dec. 2014.
13. *The Remarriage of Mathematics and Physics*, Plenary Talk, IMS Annual Meeting, ISM-Dhanbad, India, Dec. 2014.

14. *Stringy Symmetries and the Higher Spin Square*, ICTS Discussion Meeting Talk, Bangalore, Feb. 2015.

15. *From Higher Spins to Strings (3 lectures)*, ICTP Spring School, Trieste, Italy, Mar. 2015.

16. *Simplifying String Theory*, HRI Review, Allahabad, India, Mar. 2015.

Academic recognition/Awards:

- Elected Fellow, National Academy of Sciences, India (NASI), 2014.
- J. C. Bose Fellowship of the DST, Govt. of India., 2015.

Other Activities:

1. Co-Chair, Indo-UK Frontiers of Science (Royal Society, UK- DST, India),

2. External Scientific Director, ICTP Spring School on String Theory, ASICTP (2014-16).

3. Member, Organising Committee, Strings 2015, ICTS-TIFR.

4. Member/convenor of various academic and administrative committees at HRI.

Dileep P. Jatkar

Research Summary:

We show that the Ashtekar-Magnon-Das (AMD) mass and other conserved quantities are equivalent to the Kounterterm charges in the asymptotically AdS spacetimes that satisfy the Einstein equations, if we assume the same asymptotic fall-off behavior of the Weyl tensor as considered by AMD. This therefore implies that, in all dimensions, the conformal mass can be directly derived from the bulk action and the boundary terms, which are written in terms of the extrinsic curvature.

In another work we show that the physical information given by conserved charges for asymptotically AdS spacetimes in Einstein-Gauss-Bonnet AdS gravity is encoded in the electric part of the Weyl tensor. This result generalizes the conformal mass definition by Ashtekar-Magnon-Das (AMD) to a gravity theory with a Gauss-Bonnet term. This proof makes use of the Noether charges obtained from an action renormalized by the addition of counterterms which depend on the extrinsic curvature (Kounterterms). If the asymptotic fall-off behaviour of the Weyl tensor is same as the one considered in the AMD method, then the Kounterterm charges and the AMD charges agree in any dimension.

Publications:

1. Dileep P. Jatkar, Georgios Kofinas, Olivera Miskovic, Rodrigo Olea, *Conformal Mass in AdS gravity,* arXiv:1404.1411 [hep-th] **Phys.Rev. D89, 12, 124010 (2014)** .

2. Dileep P. Jatkar, Georgios Kofinas, Olivera Miskovic, Rodrigo Olea, *Conformal mass in Einstein-Gauss-Bonnet AdS gravity,* arXiv:1501.06861 [hep-th] **Phys.Rev. D91, 10, 105030 (2015)** .

Conference/Workshops Attended:

1. *Indian Strings Meeting 2014*, India, December 2014.

Visits to other Institutes:

1. International Centre for Theoretical Sciences, Bengaluru, India, December 2014,
2. Indian Institute of Science Education and Research, Pune, India, December 2014,
3. Shiv Nadar University, NOIDA, India, February 2015,
4. Institute of Mathematical Sciences, Chennai, India, February 2015,
5. Indian Institute of Science, Bengaluru, India, February 2015.

Invited Lectures/Seminars:

1. *FPR and Stokes Phenomena*, Shiv Nadar University, NOIDA, India, February 2015,
2. *FPR and Stokes Phenomena*, Institute of Mathematical Sciences, Chennai, India, February 2015,
3. *FPR and Stokes Phenomena*, Indian Institute of Science, Bengaluru, India, February 2015.

Anshuman Maharana

Research Summary:

The precision Cosmic Microwave Background (CMB) observations in the last decade have charted out in detail the inhomogeneities in the CMB. The inflationary paradigm has been highly successful in providing explanations for the structure and patterns in these inhomogeneities. One of the most interesting aspects of inflation is that models of inflation are sensitive to the physics at the Planck scale – reliable construction of models requires input from quantum gravity. In the past year, I have been studying inflationary models in string theory (one of the leading candidates for a theory of quantum gravity). The key result obtained in this line of research is understanding the effect of moduli particles (a type of scalar particles generically present in string models) on inflationary predictions. The effect is interesting as it implies that the inflationary predictions of any model is highly sensitive to its embedding in string theory.

I have also been involved in performing a detailed analysis of supersymmetry breaking in some flux compatification models obtained from type IIB string theory.

Publications:

1. Koushik Dutta and Anshuman Maharana
   Inflationary Constraints on Modulus Dominated Cosmology
   Phys. Rev. D 91, 043503 (2015)

2. L. Aparicio, M. Cicoli, S. Krippendorf, A.Maharana, F. Muia and F. Quevedo; *Sequestered de Sitter String Scenarios: Soft-terms*
   JHEP 1411 (2014) 071

3. Michele Cicoli, Koushik Dutta and Anshuman Maharana
   N-flation with Hierarchically Light Axions in String Compactifications
   JHEP 1411 (2014) 071

Conference/Workshops Attended:

1. *String/M-theory Compactifications and Moduli Stabilisation*, USA, March 2015

2. *KEK Theory Workshop 2015*, Japan, January 2015

3. *Indian Strings Meeting 2014*, India, December 2014
4. *XXI DAE-BRNS Symposium on High Energy Physics 2014*, India, December 2014
5. *International conference on New Trends in field theories*, India, December 2014
6. *String Phenomenology 2014*, Italy, July 2014

Visits to other Institutes:

1. KEK, Japan, January 2015

Invited Lectures/Seminars:

1. *Inflation, Moduli and the CMB*, UK-India Scientific Seminar on Strings and Higher Spins, Swansea, UK, March 2015
2. *Inflation, Moduli and the CMB*, KITP High Energy Theory Seminar, Santa Barbara, USA, March 2015
3. *Inflation, Moduli and the CMB*, String/M-theory Compactifications and Moduli Stabilisation, Michigan Centre for Theoretical Physics, Ann Arbor, USA, March 2015
4. *Inflation, Moduli and the CMB*, KEK Theory Workshop, KEK, Japan, January 2015
5. *Inflation, Moduli and the CMB*, Seminar in Program on Particle Theory, HKUST Jockey Club IAS, Hong Kong, January 2015
6. *Inflation and Moduli Fields*, XXI DAE-BRNS Symposium on High Energy Physics 2014, IIT Guwahati, India December 2014
7. *Inflation and Moduli Fields*, International conference on New Trends in Field Theories, BHU, Varanasi, India, November 2014
8. *Nflation in type IIB*, Conference on String Phenomenology, ICTP, Trieste, Italy, July 2014

Other Activities:

1. Supervision of visiting masters student Mr. Arpan Saha
2. Taught Quantum Field theory II in Republic Term 2014

Pinaki Majumdar

Research Summary:

There are two aspects to our work: (i) The development of a many body method that builds in, progressively, the classical and quantum fluctuations on a mean field state, and finally the low temperature tunneling effects that construct the many body ground state. (ii) The use of this method, in its first non trivial form, to study phase transitions, transport, and pseudogap effects in superconductors, magnets, and the bosonic superfluid-Mott problem. The superconducting problems have been studied in the presence of large population imbalance, exploring the breached pair and Fulde-Ferrell-Larkin-Ovchinnikov regimes, the repulsive fermion problems have been solved on the frustrated checkerboard and pyrochlore lattices, while the Bose Hubbard model has been solved at finite temperature to obtain a phase diagram remarkably similar to the full quantum Monte Carlo result. We are also working on materials in a heterostructure geometry.

Publications:

1. Anamitra Mukherjee and Pinaki Majumdar, *A real space description of magnetic field induced melting in the charge ordered manganites: I. The clean limit*, Eur. Phys. J. B, **87**, 238, (2014).

2. Anamitra Mukherjee and Pinaki Majumdar, *A real space description of magnetic field induced melting in the charge ordered manganites: II. The disordered case*, Eur. Phys. J. B, **87**, 239, (2014).

3. Sabyasachi Tarat and Pinaki Majumdar, *A real space auxiliary field approach to the BCS-BEC crossover,* Eur. Phys. J. B, **88**, 68, (2015).

4. Rajarshi Tiwari and Pinaki Majumdar, *Spectroscopic signatures of the Mott transition on the anisotropic triangular lattice,* Europhys. Lett, **108**, 27007, (2014).

Preprints:

1. Madhuparna Karmakar and Pinaki Majumdar, *Strong coupling s-wave superconductors in the extreme Pauli limit: I. The breached pair and metastable FFLO phases,* arXiv:1409.4025.

2. Nyayabanta Swain, Rajarshi Tiwari and Pinaki Majumdar, *Mott-Hubbard transition on the pyrochlore lattice*, arXiv:1505.03502.

Invited Lectures/Seminars:

1. *The Mott transition on frustrated lattices*, Institute Colloquium, S. N. Bose National Center, Kolkata, May 2014.

2. *Quantum matter: experiments, theory and simulation*, DST Sponsored School, Sam Higginbottom University, Allahabad, April 2014.

3. *Visualising quantum matter*, Science Conclave, I.I.I.T Allahabad, Allahabad, Dec 2014.

Other Activities:

1. Taught the Advanced Quantum and Statistical Mechanics course during Aug-Dec 2014, and the Statistical Mechanics course during Jan-Apr 2015.

Biswarup Mukhopadhyaya

Research Summary:

A series of studies on possible new physics in the Higgs data has been carried out. This includes a proposal of certain observable measurements at the high-energy run of the LHC, which could be indicative of higher-dimensional anomalous interactions of the HIggs with pairs of gauge bosons. The simultanoeus viability of discerning such interactions at electron-positron colliders serving as Higgs factories has also been investigated (with Shankha Banerjee, Tanumoy Mandal, Bruce Mellado, Gilad Amar, Stefan von Buddenbrock, Alan S. Cornell).

The High-scale validity of a two-Higgs doublet scenario has been explored in detail, exaamining the running of the mass and couplings via renormalisation group evolution. This includes constraints such as vacuum stability, perturbative unitarity and also experimental constraints from precision tests as well as LHC data. It is founbd that, irrespective of the uncertainty in top quarl mass, a two-Higgs doublet model can be valid all the way up to the Planchk scale (with Nabarun Chakrabarty and Ujjal Kumar Dey).

The consistency of the inert doublet scenario that explains the dark matter content of the universe, laptogenesis and also as neutrino masses has been investigated. The situations where such a theory is valid upto the Planck or Grand Unification scales, while satisfying all collider constraints, have been identified (with Nabarun Chakrabarty, Dilip Kumar Ghosh and Ipsita Saha).

The possibility of identifying a light (leass than 100 GeV in mass) elusive geometric field named radion at the LHC has been studied. Taking the diphoton channel and considering all experimental limitations into account, we have come with event selection criteria that can isolate such a particle with sufficient statistical significance. (with Ushoshi Maitra, Santosh Kumar Rai, Satyaki Bhattacharya, Mariana Frank and Katri Huitu).

A variant of the type-3 seesaw scenario for neutrino masses, which generates a fermionic dark matter via a Z_2 symmetry, has been developed. The viability of the proposed model has been established taking into account all constraints from relic density as well as direct dark matter search experiments (with Avinanda Chaudhuri, Najimuddin Khan and Subhendu Rakshit).

A supersymmetric scenario with the scalar partner of a left-handed neutrino as dark matter candidate has been investigated. The constraints on this from direct dark matter search can be circumvented by postulating a scalar-pseudoscalar mass split in the sneutrino sector. A remarkable consequence of this has been pointed out for the first time, namely, the possibility of seeing same-sign trileptons at the LHC, something that is very rare in supersymnnetry signals (with Nabarun Chakrabarty and Arindam Chatterjee).

A supersymmetric scenario with the scalar partner of the botton quark as the co-annihilator of the dark matter candidate has been studied. It is shown how the strategy of constraining strongly interacting superparticle masses from LHC data changes in this scenario (with Arindam Chatterjee, Arghya Choudhury and Amitava Datta).

A muon collider is envisioned as a potential Higgs factory. It has been pointed out how such a collider can also help in unravelling a two-Higgs doublet scenario via the phenomenon of radiative return (with Nabarun Chabarty, Tao Hn and Zhen Liu).

An LHC-based study of vectorlike fermions has been carried out. Prescriptions of distinguishing between top-like and botton-like fermions have been suggested (with Aarti Girdhar and Monalisa Patra).

It has been established earlier by us that a Randall-Sundrum theory of warped extra dimensions can explain why our the dynamics of our universe is governed by spacetime curvature but not torsion. The robustness of this explanation against gravitational back reactions has been demonstrated (with Ashmita Das and Soumitra SenGupta).

Publications:

1. Arindam Chatterjee, Debottam Das, Biswarup Mukhopadhyaya, Santosh Kumar Rai, *Right Sneutrino Dark Matter and a Monochromatic Photon Line,* JCAP **1407**, 023, (2014)

2. Aarti Girdhar, Biswarup Mukhopadhyaya, Monalisa Patra, *Distinguishing Signatures of top-and bottom-type heavy vectorlike quarks at the LHC ,* Phys. Rev. **D91**, 5-055015, (2015)

3. Gilad Amar, Shankha Banerjee, Stefan von Buddenbrock, Alan S. Cornell, Tanumoy Mandal, Bruce Mellado, Biswarup Mukhopadhyaya, *Exploration of the tensor structure of the Higgs boson coupling to weak bosons in e+ e— collisions,* JHEP **1502**, 128, (2015)

4. Nabarun Chakrabarty, Ujjal Kumar Dey, Biswarup Mukhopadhyaya, *High-scale validity of a two-Higgs doublet scenario: a study including LHC data,* JHEP **1412**, 166, (2014)

5. Nabarun Chakrabarty, Tao Han, Zhen Liu, Biswarup Mukhopadhyaya, *Radiative Return for Heavy Higgs Boson at a Muon Collider,* Phys. Rev. **D91**, 1-015009, (2015)

6. Nabarun Chakrabarty, Ujjal Kumar Dey, Biswarup Mukhopadhyaya, *High-scale validity of a two-Higgs doublet scenario: a study including LHC data,* JHEP **1412**, 166, (2014)

7. Satyaki Bhattachaeya, Mariana Frank, Katri Huitu, Ushoshi Maitra, Biswarup Mukhopadhyaya, Santosh Kumar Rai, *Probing the light radion through diphotons at the Large Hadron Collider,* Phys. Rev. **D91**, 016008, (2014)

8. Ashmita Das, Biswarup Mukhopadhyaya, Soumitra SenGupta, *Why has spacetime torsion such negligible effect on the Universe?,* Phys. Rev. **D90**, 10-107901, (2014)

9. Arindam Chatterjee, Arghya Choudhury, Amitava Datta, Biswarup Mukhopadhyaya, *Gluino mass limits with sbottom NLSP in coannihilation scenarios,* JHEP. **D1501**, 154, (2015)

10. Avinanda Chaudhuri, Najimuddin Khan, Biswarup Mukhopadhyaya, Subhendu Rakshit, *Dark matter candidate in an extended type III seesaw scenario ,* Phys. Rev. **D91**, 055024, (2015)

Preprints:

1. Arindam Chatterjee, Nabarun Chakrabarty, Biswarup Mukhopadhyaya, *Same-sign tri-leptons with a left-sneutrino as the lightest minimal supersymmetric particle ,* arXiv:1411.7226 [hep-ph]

2. Nabarun Chakrabarty, Dilip Kumar Ghosh, Biswarup Mukhopadhyaya, IPsita Saha, *Dark matter, neutrino masses and high scale validity of an inert Higgs doublet model ,* arXiv:1501.03700 [hep-ph]

3. Shankha Banerjee, Tanumoy Mandal, Bruce Mellado, Biswarup Mukhopadhyaya, *Cornering Dimension-6 HVV Interactions at High Luminosity LHC: The Role of Event Ratios ,* arXiv:1505.00226 [hep-ph]

4. Siddharth Dwivedi, Dilip KUmar Ghosh, Biswarup Mukhopadhyaya, Ambresh Shivaji, *Constraints on CP-Odd Gauge-Higgs Operators* , arXiv:1505.05844 [hep-ph]

5. Stefan von Buddenbrock, Nabarun Chakrabarty, Alan Cornell, Deepak Kar, Tanumoy Mandal, Mukesh Kumar, Bruce Mellado, Biswarup Mukhopadhyaya, *Explaining the Higgs boson pT distributions with a new heavy scalar boson and a dark matter candidate,* e-Print: arXiv:1506.00612 [hep-ph]

Conference/Workshops Attended:

1. *Kruger-2014*, South Africa, December, 2014
2. *DAE Symposium on High Energy Physics*, Guwahati, India, December, 2014
3. *Workshop on LHC and Dark Matter*, Kolkata, India, February, 2015

Visits to other Institutes:

1. National Centre for Radio Astronomy, Pune, India, April, 2014.
2. University of Helsinki, Finland, India, April, 2014.
3. Indian Institute of Science, Bangalore, Bangalore, India, August, 2014.
4. Indian Association for the Cultivation of Science, Kolkata, June-July, 2014.
5. Cotton University, Gueahati, India, November, 2014.
6. University of Witwatersrand, Johannesburg, South Africa, December, 2014.
7. Indian Institute of Technology, Guwahati, India, December, 2014.
8. Indian Association for the Culktivation of Science, Kolkata, India, February, February, 2015.
9. Institute of Mathematical Sciences, Chennai, India, March, 2015.
10. Jamia Milia University, Delhi, India, March, 2015.

Invited Lectures/Seminars:

1. *A discovery studded with ignorance: some hopes and fears with elementary particles*, Colloquium given at National Centre for radio Astronomy, Pune, India, April, 2014.

2. *The Higgs boson as the gateway to new physics*,Seminar given at University of Helsinki, Helsinki, Finland, May, 2014.

3. *Knowable unknowns about elementary particles*, Colloquium given at Cotton University, Guwahati, India, November, 2014.

4. *Still the supersymmetric path? To tread or not to tread*, Keynote address at Kruger-2014, South Africa, December, 2014.

5. *Must all rambling about SUSY today be cynical?*, Talk given at the Workshop on LHC and Dark Matter, Indian Association for the Cultivation of Science, Kolkata, , February, 2015.

6. *The messiah of mass and message about more*, Colloquium given at Institute of Mathematical Sciences, Chennai, India, March, 2015.

7. *From quantum mechanics to quantized fields— why and how*, Set of pedagodical lectures at Jamia Centre for Theoretical Physics, Jamia Milia University, Delhi, India, March, 2015.

Other Activities:

1. Continued as Co-ordinator, Regional Centre for Accelerator-based Particle Physics, HRI.

2. Taught a course on Quantum Field Theory-1

3. Supervised the thesis work of 6 Ph.D. students on the average throughout the year, 1 Master's thesis of IISER, Bhopal, and several visiting students..

4. Served on several committees of HRI.

G Venketeswara Pai

Research Summary:

My research focuses on strongly correlated electron systems and cold atoms as quantum simulators. Specific problems include studying the competition between antiferromagnetic insulating phase stabilised by local Coulomb interaction among electrons and charge density wave or bipolaronic insulating phase stabilised by local electron-phonon interaction in the Holstein-Hubbard model, onset and evolution of superconductivity as the fraction of attractive centres are varied in a metal or an insulator. 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.

Preprints:

1. *The Hubbard-Holstein Model at Half-filling : A Static Auxiliary Field Study*
   with Saurabh Pradhan (in preparation)

2. *Effect of Site Dilution in the Two Dimensional Attractive Hubbard Model*
   with Saurabh Pradhan (in preparation)

Other Activities:

1. Guided a visiting project student, Sayan Basak (IIT Kanpur) during May-July 2014

2. Taught a graduate level course, Condensed Matter Physics - I, during August-December 2014

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

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

Tribhuvan Prasad Pareek

Research Summary:

We have studied the generic **Topological liquids** using an exact(non-adiabatic,non-perturbative) density matrix scattering theory for a two component quantum liquid which interacts or scatters off from a generic spin-dependent quantum potential. The generic spin dependent quantum potential[eq.(1)] is a **matrix potential**, hence, adiabaticity criterion is ill-defined. Therefore the full **matrix potential** should be treated non-adiabatically. We succeed in doing so using the notion of **vectorial matrices** which allows us to obtain an exact analytical expression for the scattered density matrix ,ϱ_{sc}. We find that the number or charge density in scattered fluid,Tr(ϱ_{sc}), expressions in eqs. (**??**) depends on non-trivial quantum interference coefficients, $\mathcal{Q}^{\alpha\beta}_{0ijk}$ which arises due to quantum interference between spin-independent and spin-dependent scattering amplitudes and among spin-dependent scattering amplitudes. Further it is shown that Tr(ϱ_{sc}) can be expressed in a compact form where the effect of quantum interference coefficients can be include using a vector $\boldsymbol{Q}^{\alpha\beta}$ which allows us to define a **vector order parameter $\boldsymbol{Q}$**. Since the number density is obtained using and exact scattered density matrix, therefore, we do not need to prove that $\boldsymbol{Q}$ is non-zero. However for sake of completeness we make detailed mathematical analysis for the conditions under which the **vector order parameter $\boldsymbol{Q}$** would be zero or non-zero. We find that in presence of spin-dependent interaction the **vector order parameter $\boldsymbol{Q}$** is necessarily non-zero and is related to the commutator and anti-commutator of scattering matrix $\mathcal{S}$ with its dagger $\mathcal{S}^{\dagger}$[eq.(**??**)]. It is further shown that $\boldsymbol{Q} \neq 0$, implies four physically equivalent conditions,i.e, **spin-orbital entanglement is non-zero**, **Non-Abelian scattering phase ,i.e, matrices**, scattering matrix is **Non-Unitary** and the broken time reversal symmetry for scattered density matrix. This also implies that quasi particle excitation are anyonic in nature, hence, charge fractionalization is a natural consequence. This aspect has also been discussed from the perspective of number or charge density conservation, which implies i.e, Tr(ϱ_{sc}) = Tr(ϱ_{in}). On the other hand $\boldsymbol{Q} = 0$ turns out to be a mathematically forced unphysical solution in presence of spin-dependent potential or scattering which is equivalent to **Abelian** hydrodynamics ,**Unitary** scattering matrix, absence of spin-space entanglement, and preserved time reversal symmetry.

Publications:

1. Tribhuvan Prasad Pareek *Quantum non-Abelian hydrodynamics: Anyonic or spinorbital entangled liquids, nonunitarity of scattering matrix and charge fractionalization* IJMPB 29-02, 1450241, (2015)

Preprints:

1. Tribhuvan Prasad Pareek *Topological liquids and Quantum Non-abelian dynamics* (manuscript under preparation)

2. Trilochan Bagarati and Tribhuvan Prasad Pareek *Toplogical phase of density matrices* (in preparation)

Conference/Workshops Attended:

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

Other Activities:

1. Organizer on "School on Topological Quantum Matter" HRI Allahabad 2015. Have been memeber of various committies of the institute.

ACADEMIC REPORT OF A. K. PATI FOR 2014-2015

0.1 ARUN KUMAR PATI

0.1.1 Research Summary:

Violation of Invariance of Entanglement Under Local PT Symmetric Unitary: Entanglement is one of the key feature of quantum world and any entanglement measure must satisfy some basic laws. Most important of them is the invariance of entanglement under local unitary operations. We show that this is no longer true with local PT symmetric unitary operations. If two parties share a maximally entangled state, then under local PT symmetric unitary evolution the entropy of entanglement for pure bipartite states does not remain invariant. Furthermore, we show that if one of the party has access to PT-symmetric quantum world, then a maximally entangled state in usual quantum theory appears as a non-maximally entangled states for the other party. This we call as the "entanglement mismatch" effect which can lead to the violation of the no-signaling condition.

Quantum Theory Allows Measurement of Non-Hermitian Operators: In quantum theory, a physical observable is represented by a Hermitian operator as it admits real eigenvalues. This stems from the fact that any measuring apparatus that is supposed to measure a physical observable will always yield a real number. However, reality of eigenvalue of some operator does not mean that it is necessarily Hermitian. There are examples of non-Hermitian operators which may admit real eigenvalues under some symmetry conditions. One may wonder if there is any way to measure a non-Hermitian operator, for example, the average of a non-Hermitian operator in a quantum state. We show that quantum theory allows direct measurement of any non-Hermitian operator via the weak measurement. The average of a non-Hermitian operator in a pure state is a complex multiple of the weak value of the positive semi-definite part of the non-Hermitian operator. We also prove a new uncertainty relation for any two non-Hermitian operators and illustrate this for the creation and annihilation operators, and the Kraus operators.

Stronger Uncertainty Relations: The Heisenberg-Robertson uncertainty relation expresses a limitation in the possible preparations of the system by giving a lower bound to the product of the variances of two observables in terms of their commutator. Notably, it does not capture the concept of incompatible observables because it can be trivial, i.e., the lower bound can be null even for two non-compatible observables. Here we give two stronger uncertainty relations, relating to the sum of variances, whose lower bound is guaranteed to be nontrivial whenever the two observables are incompatible on the state of the system.

Interference Visibility, Entanglement and Quantum Correlation: In quantum information and communication one looks for the non-classical features like interference and quantum correlations to harness the true power of composite systems. We show how the concept akin to interference is, in fact, intertwined in a quantitative manner to entanglement and quantum correlation. In particular, we prove that the difference in the squared visibility for a density operator before and after a complete measurement, averaged over all unitary evolutions, is directly related to the quantum correlation measure based on the measurement disturbance. For pure and mixed bipartite states the unitary average of the squared visibility is related to entanglement measure. This may constitute direct detection of entanglement and quantum correlations with quantum interference setups. Furthermore, we prove that for a fixed purity of the subsystem state, there is a complementarity relation between the linear entanglement of formation and the measurement disturbance. This brings out a quantitative difference between two kinds of quantum correlations.

Monogamy and Polygamy Properties of Entanglement of Purification: For bipartite pure and mixed quantum states, in addition to the quantum mutual information, there is another measure of total correlation, namely, the entanglement of purification. We study the monogamy, polygamy, and additivity properties of the entanglement of purification for pure and mixed states. In this paper, we show that, in contrast to the quantum mutual information which is strictly monogamous for any tripartite pure states, the entanglement of purification is polygamous for the same. This shows that there can be genuinely two types of total correlation across any bipartite cross in a pure tripartite state. Furthermore, we find the lower bound and actual values of the entanglement of purification for different classes of tripartite and higher-dimensional bipartite mixed states. Thereafter, we show that if entanglement of purification is not additive on tensor product states, it is actually subadditive. Using these results, we identify some states which are additive on tensor products for entanglement of purification. The implications of these findings on the quantum advantage of dense coding are briefly discussed, whereby we show that for tripartite pure states, it is strictly monogamous and if it is nonadditive, then it is superadditive on tensor product states.

Duality of Quantum Coherence and Path Distinguishability: We derive a generalized wave-particle duality relation for arbitrary dimensional multi-path quantum interference phenomena. Beyond the traditional signature of the wave nature of a quantum system, i.e., the fringe visibility, we introduce a novel quantifier as the normalized quantum coherence, recently defined in the frame-work of quantum information theory. To witness the particle nature, we quantify the path distinguishability or the which-path information based on unambiguous quantum state discrimination. Then, the Bohr complementarity principle, for multi-path quantum interference, can be stated as a duality relation between the quantum coherence and the path distinguishability. For two-path interference, the quantum coherence is identical to the interference fringe visibility, and the relation reduces to the well-know complementarity relation. The new duality relation continues to hold in the case where mixedness is introduced due to possible decoherence effects.

Stronger Error Disturbance Relations in Quantum Measurements: We formulate three new error disturbance relations, one of which is free from explicit dependence upon intrinsic fluctuations of observables. The first error-disturbance relation is tighter than the one provided by the Branciard inequality and the Ozawa inequality for some initial states. Other two error disturbance relations provide a tighter bound to Ozawa's error disturbance relation and one of them is in fact tighter than the bound provided by Branciard's inequality for a small number of states.

0.1.2 Publications:

1. L. Maccone and A. K. Pati,
   Stronger Uncertainty Relations for All Incompatible Observables,
   Phys. Rev. Lett. **113**, 260401 (2014).

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

Preprints:

1. U. Singh, M. N. Bera, H. S. Dhar, A. K. Pati, *Maximally coherent mixed states: Complementarity between maximal coherence and mixedness*, arXiv:1503.06303 (2015).

2. C. Mukhopadhyay, N. Shukla, A. K. Pati, *Stronger Error Disturbance Relations for Incompatible Quantum Measurements*, arXiv:1503.05085 (2015).

3. M. N. Bera, T. Qureshi, M. A. Siddiqui, A. K. Pati, *Duality of Quantum Coherence and Path Distinguishability*, arXiv:1503.02990 (2015).

4. P. Agrawal, I. Chakrabarty, Sk. Sazim and A. K. Pati, *Quantum Discord has local and nonlocal quantumness*, arXiv:1502.00857 (2015).

5. S. Kim, J. Wu, M. Cho and A. K. Pati, *The Difference of Quantum State and Outcome Quantum State Induced by Quantum Measurement*, arXiv:1501.02545 (2015).

6. A. K. Pati and J. Wu, *Uncertainty and Complementarity Relations in Weak Measurement*, arXiv:1411.7218 (2014).

7. A. K. Pati, J. Wu, *Conditions for Anomalous Weak Value*, arXiv:1410.5221 (2014).

8. L. Zhang, A. K. Pati, J. Wu, *Interference Visibility as a Witness of Entanglement and Quantum Correlation*, arXiv:1407.6460 (2014).

9. A. Misra, A. Biswas, A. K. Pati, A. Sen De, U. Sen, *Quantum Correlation with Sandwiched Relative Entropies*, arXiv:1406.5065 (2014).

10. A. K. Pati, U. Singh, U. Sinha, *Quantum Theory Allows Measurement of Non-Hermitian Operators*, arXiv:1406.3007 (2014).

11. A. K. Pati, *Violation of Invariance of Entanglement Under Local PT Symmetric Unitary* arXiv:1404.6166 (2014).

Visits to other Institutes:

1. Visited Prof. Junde Wu, Zhejiang University, Hangzhou, China during June 14-July 28, 2014 as K. P. Chair Professor.

2. Visited Prof. Junde Wu, Zhejiang University, Hangzhou, China during Sept 12-Nov 28, 2014 as K. P. Chair Professor.

3. Visited Prof. J. L. Chen at Chern Institute of Mathematics, Tianjin, China during Nov 11-12, 2015.

4. Visited Dr U. Sinha at Raman Research Institite, Bangalore during August 12-14th, 2014.

5. Visited Prof. P. Agrawal, Institute of Physics during Dec 1, 2014- to Jan 22, 2015.

Invited Lectures/Seminars:

1. Invited speaker at Summer School on Quantum Information at Department of Mathematics, Zhejiang University, Hangzhou, China during July 12-July 27, 2014.

2. Delivered colloquium at Institute of Physics, Bhubaneswar on August 18, 2014.

3. Seminar on "Weak Value and Measurement of Non-Hermitian Operators" at Chern Institute of Mathematics, Tianjin, China on Nov 12, 2014.

4. Invited speaker at workshop on "Recent developments in quantum theories" during February 20-24, 2015 under UGC networking program at Department of Physics, Banaras Hindu University, Varanasi.

0.1.3 Academic recognition/Awards:

- Honored with K. P. Chair Professor in Zhejiang University, Hangzhou, China for 2013-2015.

- The discovery of the stronger uncertainty relations beyond Heisenberg's relation is highlighted in January 2015 issue of NATURA ASIA (http://www.natureasia.com/en/nindia/article/10.1038/nindia.2015.6).

Other Activities:

1. International Advisory Committee for EMN Quantum Technology Meeting to be held during April 14-17, 2015, Beijing, China.

2. Member of the Organizing Committee for the three day discussion meeting on Quantum Measurements held at the Indian Institute of Science, Bangalore, India, during 22-24 October 2014.

3. Guided visiting students in the area of Quantum Information.

4. Evaluated Ph.D. thesis from Kolkata University.
5. Guiding four Ph.D. students in the area of Quantum Information from HRI, Allahabad.

Santosh Kumar Rai

Research Summary:

During last year my area of research has been on various new ideas that propose physics beyond the Standard Model (SM) of particle physics. I have been working on models with extra scalar singlets and vector fermions, left-right supersymmetric theories and their implications in collider experiments such as the Large Hadron Collider (LHC).

In particular, we considered an extension of the Standard Model involving a singlet Higgs and down type vector-like quarks in the light of the current LHC Higgs data. For a good range of the parameters of the Higgs potential, and a mass range for the heavy vector-like quark, we find that the singlet heavy Higgs arising from the production and decay of the vector-like quarks give rise to (2b 4t) signal. The subsequent decay of the top quarks to bW^+ give rise to a final state with six b quarks, two same-sign charged leptons and missing transverse momenta with observable cross-sections at the 14 TeV run of the Large Hadron Collider. The Standard Model background for such a final state is found to be practically negligible.

I also worked on the minimal left-right supersymmetric model where we analysed the parameter space of the model using the observed Higgs data. The model contains left- and right-handed fermionic doublets, two Higgs bidoublets, two Higgs triplet representations, and one singlet, insuring a charge-conserving vacuum. We impose the condition that the model complies with the experimental constraints on supersymmetric particles masses and on the doubly-charged Higgs bosons, and require that the parameter space of the model satisfy the LHC data on neutral Higgs signal strengths at 2σ. We choose benchmark scenarios by fixing some basic parameters and scanning over the rest. The LSP in our scenarios is always the lightest neutralino. We find that the signals for $h \to \gamma\gamma$ and $h \to VV^*$ are correlated, while $h \to b\bar{b}$ is anti-correlated with all the other decay modes, and also that the contribution from singly-charged scalars dominate that of the doubly-charged scalars in $h \to \gamma\gamma$ and $h \to Z\gamma$ loops, contrary to Type-II seesaw models. We also illustrate the range for mass spectrum of the LRSUSY model in light of planned measurements of the branching ratio of $h \to \gamma\gamma$ to 10% level.

In another work we studied a radion in a scenario with a warped extra dimension which can be lighter than the Higgs boson, even if the Kaluza-Klein excitation modes of the graviton turn out to be in the multi-TeV region. The discovery of such a light radion would be gateway to new physics. We show how the two-photon mode of decay can enable us to probe a radion in the mass range 60 - 110 GeV. We take into account the diphoton background, including fragmentation effects, and include cuts designed to suppress the background to the maximum possible extent. Our conclusion is that, with an integrated luminosity of 3000 fb^{-1} or less, the next run of the Large Hadron Collider should be able to detect a radion in this mass range, with a significance of 5 standard deviations or more.

Publications:

1. D. Karabacak, S. Nandi and Santosh Kumar Rai, *New signals for singlet Higgs and vector-like quarks at the LHC,* Phys. Lett. **B737**, 341, (2014). [arXiv:1405.0476 [hep-ph]].

2. M. Frank, D. K. Ghosh, K. Huitu, Santosh Kumar Rai, I. Saha, H. Waltari, *Left-right supersymmetry after the Higgs boson discovery,* Phys. Rev. D **90**, (2014) 11, 115021. [arXiv:1408.2423 [hep-ph]].

3. S. Bhattacharya, M. Frank, K. Huitu, U. Maitra, B. Mukhopadhyaya and Santosh Kumar Rai, *Probing the light radion through diphotons at the Large Hadron Collider,* Phys. Rev. D **91**, (2015), 016008.

Conference/Workshops Attended:

1. *LHCDM-2015* : Workshop on LHC and Dark Matter, Kolkata, India, February 2015.

Visits to other Institutes:

1. Indian Association for the Cultivation of Science, Kolkata, India, April 2014.

2. University of Helsinki and Helsinki Institute of Physics, Helsinki, Finland, May-June 2014.

Invited Lectures/Seminars:

1. *Some Higgs studies after the "Higgs" discovery*, Indian Association for the Cultivation of Science, Kolkata, India, April 2014.

2. *Some Higgs studies after the "Higgs" discovery*, Helsinki Institute of Physics, Helsinki, Finland, May-June 2014.

Other Activities:

1. Taught course at HRI integrated PhD program titled *Numerical Methods*, Aug-Dec, 2014.
2. Mentored theory projects of Mr. Samiran Roy, Mr. Dipyaman Pramanik and Ms. Juhi Dutta, Aug-Dec, 2014.
3. Member, Organising Committee of *LHCDM-2015* : Workshop on LHC and Dark Matter, Kolkata, India, Feb 2015.
4. Member, VSP Committee and Library Committee, 2014-2015.

Sumathi Rao

Research Summary:

During the period, April 2014-March 2015, I have been mainly working on topological phases of matter.

We have been studying Andreev bound levels in a hybrid junction consisting of a Weyl semi-metal sandwiched between s-wave superconductors. Due to the anisotropy of the Fermi surface around each Weyl node and due to the fact that the s-wave superconductor induces p-wave pairings as well in the Weyl semi-metal, we expect the Andreev bound levels to be different from those in normal metals or even relativistic metals like graphene. The surface states, however, being bound to the surfaces, do not appear to play any role in any of the transmissions or reflections, or in the formation of the Andreev bound levels.

We have been studying silicene, which is a layered material like graphene, but with a buckled sub-lattice structure. So unlike in graphene, which has low energy excitations, which are massless Dirac fermions, the low energy excitations of silicene are massive. However, its mass can be tuned by an electric field, and silicene phases include both massive (insulator and topological insulator phases) and massless (metal) phases. In particular, we have studied the spin polarisation and the tunneling magnetoresistance (TMR) in ferromagnet-normal metal-ferromagnet junctions. We have investigated the oscillatory behaviour of the conductances in the presence of spin-dependent and spin-independent barriers and note that this behaviour can be tuned by an external field. We have also found that the TMR can be tuned to negative values.

We are also studying the superconducting proximity effect on silicene - in particular, we are studying superconductor-ferromagnet junction in silicene and superconductor-ferromagnet-superconductor junctions.

We study resonant Andreev reflections in a multi-terminal device connected to a p-wave superconductor and compute the conductances and the cross current-current noise correlations in the different leads. At zero energy, the same results can also be obtained by coupling the multiple wires with a Majorana fermion by a tunneling Hamiltonian, provided the appropriate identifications of the tunnelings with the scattering matrix elements are done. We are also studying the behaviour of the cross correlations as a function of the asymmetry between the wires and also as a function of a time-reversal breaking parameter.

Other aspects of topological phases that we have been studying include proximity to unconventional superconductors (p-wave, d-wave, states with non-zero momentum Cooper pairs (FFLO), etc). We have also been looking at surface states of Weyl semi-metals with more than 2 Weyl nodes with the aim of understanding how Fermi arcs intersect.

Publications:

1. Udit Khanna, Arijit Kundu, Saurabh Pradhan and Sumathi Rao, *Proximity induced superconductivity in Weyl semi-metals*, Phys. Rev. **B90**, 195430 (2014).

2. P. Shastri, A. Kurup, L. Resmi, R. Ramaswamy, S. Ubale, S. Bagchi, Sumathi Rao and S. Narasimhan *Towards gender equity in physics in India: Initiatives, investigations and questions*, Proceedings of the International conference on Women in Physics, Waterloo, Canada.

Preprints:

1. Ruchi Saxena, Arijit Saha and Sumathi Rao, *Spin polarisation and tunnelling magneto-resistance in ferromagnetic-normal metal-ferromagnetic junctions of Silicene* (in preparation)

2. Ruchi Saxena, Arijit Saha and Sumathi Rao, *Superconducting proximity effect in ferromagnetic silicene*, (in preparation)

3. Krashna Mohan Tripathy, Sourin Das and Sumathi Rao,*Noise correlations in branched topological normal-superconductor junctions*, (in preparation)

4. Dibyakanti Mukherjee, Udit Khanna, Arijit Kundu and Sumathi Rao, *Crossed Andreev transmission and Andreev bound states in NSNSN junctions of Weyl semi-metals* (in preparation)

5. Priyanka Mohan and Sumathi Rao, *Slave fermions in quantum spin chains* (in preparation)

Conference/Workshops Attended:

1. International conference on *New Trends in Field Theories*, Nov 1-5, 2014 at Banaras Hindu University, Varanasi.

Visits to other Institutes:

1. Visit to International Centre for Theoretical Sciences (ICTS), Bangalore, 2-20 June, 2014
2. Visit to Dept of Physics, Ramakrishna Mission Vivekananda University, 4-5 November, 2014
3. Planning committee meeting for SERC school at Ramakrishna Mission Vivekananda University (RKMVU) , 5th November, 2014
4. SG-10 meeting on 19th November, 2014, BARC, Mumbai
5. Visit to Tezpur University, 6-20 January, 2015

Invited Lectures/Seminars:

1. *Introductory lecture on topological insulators and Weyl semi-metals*, Dept of Physics, RKMVU, 4th November, 2014
2. *Weyl fermions in condensed matter systems*, Dept of Physics, BHU conference, 3 November, 2014
3. *Weyl fermions in condensed matter systems*, HRI, 13 November 2014
4. *9 lectures on relativistic quantum mechanics and its connection to real systems*, Science academies refresher course, Tezpur University, 6-20 January, 2015

Other Activities:

1. Organised a school on Topological Quantum Matter from February 9-21, 2014
2. Member, Academic council, MNNIT, Allahabad
3. Convenor, Faculty Advisory Committee and Daycare Committee, HRI
4. Member, Local works committee, Housing allotment committee, HRI
5. Taught 1/2 course CMP2 - (Jan 2015 - May 2015)

Ashoke Sen

Research Summary:

My work during April 2014 - March 2015 has been on several aspects of string theory.

1. In some string theories a massless field with a tree level potential can acquire a tachyonic mass at the one loop level, forcing us to quantize the theory around a new background that is not a solution to the classical equations of motion and hence is not described by a conformally invariant world-sheet theory. Together with Roji Pius and Arnab Rudra I developed a systematic procedure for carrying out string perturbation theory around such backgrounds. In another series of papers I developed a general procedure for computing off-shell amplitudes in superstring theory and introduced the notion and construction of 1PI effective action that can be used to systematically address the problem of vacuum shift and mass renormalization in superstring theory.

2. In a paper with Michele Del Zotto, I showed how the Coulomb branch formula, developed earlier in collaboration with Pioline and Manschot, can be used to show the absence of exotics in a wide class of N=2 supersymmetric gauge theories.

3. Exact results for the BPS index are known for a class of BPS dyons in type II string theory compactified on a six dimensional torus. In a paper with Abhishek Chowdhury, Richard Garavuso and Swapnamay Mondal, we set up the problem of counting the same BPS states in a duality frame in which the states carry only Ramond-Ramond charges. We explicitly count the number of states carrying the lowest possible charges and find agreement with the result obtained in other duality frames. Furthermore, we find that after factoring out the supermultiplet structure, each of these states carry zero angular momentum. This is in agreement with the prediction obtained from a representation of these states as supersymmetric black holes.

4. Together with Olaf Hohm and Barton Zwiebach, I carried out the dimensional reduction of heterotic string theory on tori keeping the full set of non-abelian gauge fields. Earlier work had only kept the fields in the Cartan subalgebra of the gauge group.

5. I suggested how the accelerated expansion of the universe discovered in the late 90's can be used to avoid vacuum decay.

Publications:

1. R. Pius, A. Rudra and A. Sen, "String Perturbation Theory Around Dynamically Shifted Vacuum," JHEP **1410**, 70 (2014) [arXiv:1404.6254 [hep-th]].
2. J. Manschot, B. Pioline and A. Sen, "The Coulomb Branch Formula for Quiver Moduli Spaces," arXiv:1404.7154 [hep-th].
3. A. Chowdhury, R. S. Garavuso, S. Mondal and A. Sen, "BPS State Counting in N=8 Supersymmetric String Theory for Pure D-brane Configurations," JHEP **1410**, 186 (2014) [arXiv:1405.0412 [hep-th]].
4. A. Sen, "Off-shell Amplitudes in Superstring Theory," Fortsch. Phys. **63**, 149 (2015) [arXiv:1408.0571 [hep-th]].
5. M. Del Zotto and A. Sen, "About the Absence of Exotics and the Coulomb Branch Formula," arXiv:1409.5442 [hep-th].
6. O. Hohm, A. Sen and B. Zwiebach, "Heterotic Effective Action and Duality Symmetries Revisited," JHEP **1502**, 079 (2015) [arXiv:1411.5696 [hep-th]].
7. A. Sen, "Gauge Invariant 1PI Effective Action for Superstring Field Theory," JHEP **1506**, 022 (2015) [arXiv:1411.7478 [hep-th]].
8. A. Sen, "Gauge Invariant 1PI Effective Superstring Field Theory: Inclusion of the Ramond Sector," arXiv:1501.00988 [hep-th], to appear in JHEP.
9. A. Sen, "Riding Gravity Away from Doomsday," arXiv:1503.08130 [hep-th].

Invited talks at Conferences / Workshops / Schools

1. Strings 2014, Princeton, USA, June 2014
2. International Conference on Recent Developments in String Theory, Ascona, Switzerland, July 2014.

3. Conference on String Field Theory and Related Aspects, SISSA, Trieste, Italy, July-August, 2014.
4. ICTP 50th Anniversary conference, ICTP, Trieste, October 2014.
5. Indian Strings Meeting, Puri, India, December 2014.
6. CERN Winter School, CERN, Geneva, February 2015.
7. ICTP Spring School, ICTP, Trieste, March-April, 2015.

Visits to other Institutes:

1. MIT, USA, May-June, 2014

Academic recognition/Awards:

- Dirac Medal, ICTP, 2014.

Courses given

1. General Relativity, August-December, 2014
2. Superstring compactification, January-April, 2015

Prasenjit Sen

Research Summary:

My research during this period was focussed on free and surface supported clusters. We studied valence transition of the V atom in cationic VAg_n^+ clusters. This explained many of the experimental observations in these class of clusters. We also studied silver clusters deposited near the step edge of a highly oriented pyrolytic graphite substrate. Apart from energetics, dynamics of Ag_5 and Ag_8 clusters at finite temperatures were studied. We also identified the right substrates for self-assembly of $FeCa_8$ magnetic superatoms. Graphene and hexagonal BN turned out to be ideal for this.

Publications:

1. A. Singh and P. Sen, *A density functional study of silver clusters on a stepped graphite surface: formation of self-assembled nano-wires,* Phys. Chem. Chem. Phys. **DOI:** 10.1039/C5CP01016K (2015)

2. A. Singh and P. Sen, *Finding the right substrate support for magnetic superatom assembly from density functional calculations,* Phys. Rev. B **91**, 035438, (2015)

3. V. M. Medel, A. C. Reber, V. Chauhan, P. Sen, A. M. Köster, P. Calaminici and S. N. Khanna, *Nature of Valence Transition and Spin Moment in Ag_nV^+ Clusters,* J Am. Chem. Soc. **136**, 8229 (2014)

Preprints:

1. A. Maity, A. Singh and P. Sen, *Peierls transition and edge reconstruction in phosphorene nanoribbons,* arXiv:1404.2469

Conference/Workshops Attended:

1. *Materials Simulations Theory And Numerics Summer School*, India, July, 2014.

2. *Multi-scale Modeling of Materials and Devices*, India, October-November, 2014.

3. *DST-SERC School on "Density Functional Theory and Beyond: Computational Materials Science and Materials Design"*, India, December 2014.

4. *Workshop on High Performance Scientific Computing*, India, May, 2014.

Visits to other Institutes:

Invited Lectures/Seminars:

1. *Novel Materials for Electronic Applications*, Workshop on High Performance Scientific Computing, Inter-University Accelerator Centre, New Delhi, May, 2014.

2. *The Importance of being the right shape: Interplay of Geometric and Electronic Structures in Atomic Clusters*, Materials Simulations Theory And Numerics Summer School, Indian Institute Science Education and Research, Pune, July 2014.

3. *Finding the right support for magnetic superatom assembly* Multi-scale Modeling of Materials and Devices, Bhabha Atomic Research Centre, Mumbai, October-November, 2014.

4. *Hybrid functionals in DFT* DST-SERC School on "Density Functional Theory and Beyond: Computational Materials Science and Materials Design", Vadodara, December, 2014.

Academic recognition/Awards:

Other Activities:

1. Organizing 3rd edition of the *International Symposium on Clusters, Cluster Assemblies and Nano-scale Materials* (ISCANM-III), March, 2014.

2. Reviewing papers for the journals *Physical Review B*, *Physical Review Letters*, *Physical Chemistry and Chemical Physics*, *Journal of Organometallic Chemistry*, *New Journal of Chemistry*, *Solid State Communications* etc.

3. Member of the Editorial Board of the Journal *Physica Scripta*.

Ujjwal Sen

Research Summary:

During the past year, the main areas of my research have been the study of different aspects of multiparty quantum states and the interface of quantum many-body physics with quantum information.

A connecting theme of the different areas pursued during the last year was monogamy. Monogamy is a non-classical property that restricts the sharability of quantum correlation among the constituents of a multipartite quantum system. We delve into the foundations of the concept of monogamy, as well as use it for several applications. In particular, we show that all quantum states can be made monogamous by considering monotonically increasing functions of quantum correlations. We also apply the concept of monogamy to quantify multisite quantum correlations, and use it to understand phenomena ranging from quantum advantage in classical information transfer to photosynthesis.

Another connecting theme is multipartite quantum correlations. There is an ongoing effort by several groups around the globe who wants to quantify multiparty quantum correlations. Our contribution to this quest includes (a) the conceptualization and providing of an efficient method to calculate the generalized geometric measure, a multiparty entanglement measure and (b) the use of monogamy constraints for information-theoretic bipartite quantum correlation measures to quantify multisite quantum correlations. Such quantification helps us to characterise and understand frustrated quantum spin systems, gapless-to-gapped transitions in quantum spin systems on low-dimensional lattices, protocols for transmission of classical information via quantum channels, constructive interference in Heisenberg spin glass models, and time dynamics in light-harvesting complexes.

Fidelity plays an important role in measuring distances between pairs of quantum states, of single as well as multiparty systems. Based on the concept of fidelity, we have introduced a physical quantity, shared purity, for arbitrary pure or mixed quantum states of shared systems of an arbitrary number of parties in arbitrary dimensions. We found that it is different from quantum correlations. However, we proved that a maximal shared purity between two parties excludes any shared purity of these parties with a third party, thus ensuring its quantum nature.

Benford's law is an empirical law predicting the distribution of the first significant digits of numbers obtained from natural phenomena and mathematical tables. It has been found to be applicable for numbers coming from a plethora of sources, varying from seismographic, biological, financial, to astronomical. We applied this law to analyze the data obtained from physical many-body systems described by the one-dimensional anisotropic quantum XY models in a transverse magnetic field. We detected the zero-temperature quantum phase transition and found that our method gives better finite-size scaling exponents for the critical point than many other known scaling exponents using measurable quantities like magnetization, entanglement, and quantum discord. We extended our analysis to the same system but at finite temperature and ouind that it also detects the finite temperature phase transition in the model. The analysis is furthermore important in that the high-precision detection of the cooperative physical phenomena is possible even from low-precision experimental data.

We have considered classical spin models of two- and three-dimensional spins with continuous symmetry and investigate the effect of a symmetry-breaking unidirectional quenched disorder on the magnetization of the system. We worked in the mean-field regime. We showed, by perturbative calculations and numerical simulations, that although the continuous symmetry of the magnetization is lost due to disorder, the system still magnetizes in specific directions, albeit with a lower value as compared to the case without disorder. The critical temperature, at which the system starts magnetizing, as well as the magnetization at low and high temperature limits, in presence of disorder, are estimated. Moreover, we treated the SO(n) n-component spin model to obtain the generalized expressions for the near-critical scalings, which suggest that the effect of disorder in magnetization increases with increasing dimension. We also studied the behavior of magnetization of the classical XY spin model in the presence of a constant magnetic field, in addition to the quenched disorder. We found that in presence of the uniform magnetic field, disorder may enhance the component of magnetization in the direction that is transverse to the disorder field.

Establishing long-range quantum correlation is an integral part of several quantum information processing tasks. We considered a process to create quasi long-range quantum discord between the non-interacting end spins of a quantum spin chain, with the end spins weakly coupled to the bulk of the chain. We found that the process is not only capable of creating long-range quantum correlation but the latter remains frozen, when certain weak end-couplings are adiabatically varied, provided they are below certain thresholds. We termed this phenomenon as adiabatic freezing of quantum correlation, which is robust to moderate thermal fluctuations. We also found that the energy gap of the system can remain frozen for the adiabatic variations. Moreover, considering the end spins as probes, we showed that the freezing length can detect the anisotropy transition in quantum XY spin chains.

Publications:

1. L. Jindal, A.D. Rane, H.S. Dhar, A. Sen(De), and U. Sen, *Patterns of Genuine Multipartite Entanglement in Frustrated Quantum Spin Systems,* Phys. Rev. A **89**, 012316 (2014)

2. A. Biswas, A. Sen(De), and U. Sen, *Shared Purity of Multipartite Quantum States,* Phys. Rev. A **89**, 032331 (2014)

3. H.S. Dhar, R. Ghosh, A. Sen(De), and U. Sen, *Cumulative quantum work-deficit versus entanglement in the dynamics of an infinite spin chain,* Phys. Lett. A **378**, 1258 (2014)

4. Salini K., R. Prabhu, A. Sen(De), and U. Sen, *Monotonically increasing functions of any quantum correlation can make all multiparty states monogamous,* Ann. Phys. **348**, 297 (2014)

5. A. Bera, D. Rakshit, M. Lewenstein, A. Sen(De), U. Sen, and J. Wehr, *Classical spin models with broken symmetry: Random Field Induced Order and Persistence of spontaneous magnetization in presence of a random field,* Phys. Rev. B **90**, 174408 (2014)

6. A. Biswas, R. Prabhu, A. Sen(De), and U. Sen, *Genuine multipartite entanglement trends in gapless-to-gapped transitions of quantum spin systems,* Phys. Rev. A **90**, 032301 (2014)

7. A. D. Rane, U. Mishra, A. Biswas, A. Sen(De), and U. Sen, *Benford's law gives better scale exponents in phase transitions of quantum XY models,* Phys. Rev. E **90**, 022144 (2014)

8. T. Das, R. Prabhu, A. Sen(De), and U. Sen, *Multipartite Dense Coding vs. Quantum Correlation: Noise Inverts Relative Capability of Information Transfer,* Phys. Rev. A **90**, 022319 (2014)

9. D. Sadhukhan, S. Singha 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)

10. A. Misra, A. Biswas, A. K. Pati, A. Sen(De), and U. Sen, *Quantum Correlation with Sandwiched Relative Entropies,* to appear in Phys. Rev. E (arXiv:1406.5065)

Preprints:

1. U. Mishra, D. Rakshit, R. Prabhu, A. Sen(De), and U. Sen, *Constructive Interference Between Disordered Couplings Enhances Multiparty Entanglement in Quantum Heisenberg Spin Glass Models,* arXiv:1408.0179
2. T. Das, Asutosh Kumar, A. K. Pal, N. Shukla, A. Sen(De), and U. Sen, *Canonical Distillation of Entanglement,* arXiv:1411.7936
3. T. Chanda, A. K. Pal, A. Biswas, A. Sen(De), and U. Sen, *To freeze or not to: Quantum correlations under local decoherence,* arXiv:1409.2096
4. T. Das, R. Prabhu, A. Sen(De), and U. Sen, *Distributed quantum dense coding with two receivers in noisy environments* arXiv:1412.6247
5. T. Chanda, U. Mishra, A. Sen(De), and U. Sen, *Time dynamics of multiparty quantum correlations indicate energy transfer route in light-harvesting complexes,* arXiv:1412.6519
6. D. Sadhukhan, R. Prabhu, A. Sen(De), and U. Sen, *Thermal Fluctuations Enhance Order-from-Disorder of Quantum Correlations in Quenched Disordered Spin Models,* arXiv:1412.8385
7. H. S. Dhar, D. Rakshit, A. Sen(De), and U. Sen, *Adiabatic freezing of long-range quantum correlations in spin chains,* arXiv:1502.01489
8. D. Sadhukhan, S. Singha Roy, D. Rakshit, R. Prabhu, A. Sen(De), and U. Sen, *Enhancement of Quantum Correlation Length in Quenched Disordered Spin Chains* arXiv:1503.04770
9. T. Chanda, T. Das, D. Sadhukhan, A. K. Pal, A. Sen(De), and U. Sen, *Reducing Computational Complexity of Quantum Correlations,* arXiv:1504.04727

Conference/Workshops Attended:

1. *"Workshop on Current Trends in Frustrated Magnetism" organized by ICTP and JNU, at JNU, New Delhi*, India, February 2015.

2. *"One day National seminar on National Science Day on the topic: Recent Advances in Physical Sciences" organized by DBT, Government of India at Udai Pratap College, Varanasi*, India, February 2015.

3. *"Entanglement from Gravity" at ICTS, Bengaluru*, India, December 2014.

Invited Lectures/Seminars:

1. *Monogamy of Correlations in Quantum World*, Meeting on Entanglement from Gravity, ICTS, Bengaluru, India, December 2014. [video available on YouTube.]

2. *Frustration from a quantum information perspective*, Workshop on Current Trends in Frustrated Magnetism, ICTP and JNU at JNU, New Delhi, India, February 2015.

3. *What is entanglement?*, One day National seminar on National Science Day on the topic: Recent Advances in Physical Sciences, DBT at Udai Pratap College, Varanasi, India, February 2015.

4. *Strong Subadditivity in Quantum Information*, Physics Colloquium, IIT Kanpur, Kanpur, India, January 2015.

5. *Resonating Valence Bonds: A quantum information perspective*, TIFR NSF Colloquium, TIFR, Mumbai, India, September 2014.

6. *Resonating Valence Bonds: A quantum information perspective*, Seminar, RRI, Bengaluru, India, September 2014.

Visits to other Institutes:

1. Institute of Physics, Bhubaneswar, India, May 2014.

2. Institute of Physics, Bhubaneswar, India, July 2014.

3. Dayalbagh Educational Institute, Agra, India, August 2014.

4. Light and Atomic Matter Physics Group, Raman Research Institute, Bengaluru, India, September 2014.
5. Tata Institute of Fundamental Research, Mumbai, India, September 2014.
6. International Centre for Theoretical Sciences, Bengaluru, India, December 2014.
7. Department of Physics, Indian Institute of Technology Kanpur, Kanpur, India, January 2015.
8. Bose Institute, Kolkata, India, January 2015.
9. School of Physical Sciences, Jawaharlal Nehru University, New Delhi, India, February 2015.
10. Udai Pratap College, Varanasi, India, February 2015.
11. Department of Applied Mathematics, University of Calcutta, Kolkata, India; Bose Institute, Kolkata, India; Institute of Physics, Bhubaneswar, India, March 2015.

Other Activities:

1. Taught a one-semester course on "Advanced Quantum Mechanics" during Jan-May 2014.
2. Taught a one-semester course on "Advanced Quantum Mechanics" during Jan-May 2015.
3. Guiding the theses of Utkarsh Mishra, Asutosh Kumar, Sudipto Singha Roy, and Sreetama Das of HRI.
4. Guiding projects of the following HRI graduate student.
   (a) Saptarshi Roy, on "Generation of pseudo-random numbers" (2014-15).
   (b) Arpita Sen, on "Infinite integrals" (2014).
5. Was in the advisory committee in the meeting "Young Quantum 2015 (YouQu-2015)" held at HRI in February 2015. The organizers were the non-faculty members of the Quantum Information and the Computation group at HRI. There were 26 speakers, 26 poster presenters, and 22 other participants. [www.hri.res.in/~youqu15/]

6. Guiding the project work of a student, Riya Sett, of Insitute of Engineering and Management, Kolkata, India, under the visiting students programme (VSP) of HRI (March-April 2015).

7. Guided the project work of a student, Divya Agrawal, Mohanlal Sukhadia University, Udaipur, India, under the visiting students programme (VSP) of HRI (summer 2014).

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

9. Serving as coordinator of the DAE project to the QIC group within the XII plan.

10. Serving as referees in national and international journals.

11. Serving as members of the PhD committees of Shrobona Bagchi, Tamoghna Das, Ushoshi Maitra, and Uttam Kumar Singh.

Shrobona Bagchi

Research Summary:

In last one year with my PhD supervisor Prof. Arun Kumar Pati and other colleagues at HRI, I have mainly worked on three different topics namely the entanglement of purification, uncertainty relations of general unitary operators and the monogamy of quantum correlations in higher dimensions. The details of my work are given below.

Monogamy, polygamy and other properties of entanglement of purification: For bipartite pure and mixed quantum states, in addition to the quantum mutual information, there is another measure of total correlation, namely, the entanglement of purification. We study various imporatnt properties of this total correlation measure, such as the monogamy, polygamy, and additivity properties of the entanglement of purification for pure and mixed states. We show that, in contrast to the quantum mutual information which is strictly monogamous for any tripartite pure states, the entanglement of purification is polygamous for the same. This shows that there can be genuinely two types of total correlation across any bipartite cross in a pure tripartite state. Furthermore, we find the lower bound and actual values of the entanglement of purification for different classes of tripartite and higher-dimensional bipartite mixed states. Thereafter, we show that if entanglement of purification is not additive on tensor product states, it is actually subadditive. Using these results, we identify some states which are additive on tensor products for entanglement of purification. The implications of these findings on the quantum advantage of dense coding are briefly discussed, whereby we show that for tripartite pure states, it is strictly monogamous and if it is nonadditive, then it is superadditive on tensor product states.

Uncertainty relations of general unitary operators: We derive a few uncertainty relations for two arbitrary unitary operators acting on physical states of any Hilbert space (finite or infinite dimensional). Our relation provides a tighter bound for two unitary Pauli operators. We also find a set of uncertainty equalities for unitary operators and discuss the implications of this finding. Apart from these, similar to the case of three canonical observables we find a new uncertainty relation for three unitary operators, and show that it cannot be obtained from the uncertainty relation of two unitary operators. In particular we find the discrete generalized displaced squeezed states for three unitary operators related to each other by discrete fourier transform. Using this, we derive the new uncertainty relation for three canonical observables as a special case of the uncertainty of such three unitary operators related by discrete fourier transform in the infinite-dimensional limit. 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.

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. Our aim is to 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.

Publications:

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

Preprints:

1. Shrobona Bagchi, Arun K Pati, *Uncertainty relations for general unitary operators*. (in preparation).

Conference/Workshops Attended:

1. Presented country poster and country paper at *ICWIP 2014 - 5th IUPAP International Conference on Women in Physics*, 05-08 August 2014, Laurier Wilfrid University, Waterloo, Canada.

2. Oral Presentation titled *Monogamy, polygamy and other properties of entanglement of purification* at *Young Quantum*, 24-26 February 2015, Harish-Chandra Research Institute, Allahabad, India.

Visits to other Institutes:

1. Institute for Quantum Computing (IQC), University of Waterloo, Ontario, Canada, August 2014.

Other Activities:

1. Examiner and invigilator at Talent Search Examination, Physics, organized by HRI for secondary and higher secondary level schools in Allahabad, November, 2014.

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. 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). In the academic year 2014-2015, I have been working with my collaborators to study the sensitivities of DUNE to CP violation, mass hierarchy and octant degeneracy. Our work studies these sensitivities for various detector configurations. We have also studied how the sensitivities get affected by various factors, such as, the knowledge of other oscillation parameters, the amount of data that can be taken in a reasonable time frame, the systematic uncertainties that compromise the data, the charge discrimination capability of the detector *etc.*. This paper is an extension on our previous work (Phys.Rev. D89 (2014) 1, 011302).

As mentioned previously, one of the main aim of DUNE is to measure the CP violating phase δ_{CP}. But, there are evidences suggesting the possibility of the existence of one (or possibly more) more generation of neutrino (of mass $\sim ev^2$) which may have small mixings with the standard model neutrinos. These extra generation of neutrino brings in extra CP phases into play. In an ongoing work with my collaborators, I have been working on how the additional phases can potentially create a degeneracy in measuring δ_{CP}.

Preprints:

1. Vernon Barger, Atri Bhattacharya, Animesh Chatterjee, Raj Gandhi, Danny Marfatia, Mehedi Masud, *Configurations of the Long-Baseline Neutrino Experiment*, arXiv:1405.1054[hep-ph]

Conference/Workshops Attended:

1. *XXI DAE-BRNS High Energy Physics Symposium 2014 at IIT, Guwahati*, India, December 2014,

Akansha Singh

Research Summary:

In one of my other work, I have studied the absorption of $FeCa_8$ cluster on three differnt type of substrates. Superatom is one of the fascinating ideas in the cluster science. By definition superatom is a cluster which is not only stable but also mimics the chemical behavior of an elemental atom or has other useful properties. In order to find the right support to form assemblies of superatoms with useful magnetic properties, we studied the adsorption of the magnetic superatom $FeCa_8$ on different types of substrates using first principles electronic structure methods. $FeCa_8$ interacts strongly with oxide and metal substrates and its structure and magnetic properties are destroyed. Interactions of $FeCa_8$ with both graphene and hexagonal BN (h-BN) are weak, and its structure is retained on these substrates. Dimers of $FeCa_8$ are also found to be stable on both h-BN and graphene. While the magnetic interaction between two $FeCa_8$ units deposited on h-BN involves only direct exchange, substrate mediated RKKY interaction also plays a role on graphene. We found that assemblies of $FeCa_8$ superatoms on h-BN will posses finite magnetic moments necessary for applications and also estimated that $FeCa_8$ superatoms will remain isolated on h-BN below a coverage of 4.97×10^{13} per cm^2. The magnetic moment of $FeCa_8$ superatoms on graphene is complicated by long range, oscillatory RKKY interactions in addition to the direct exchange. The exact magnetic structure realized in a particular assembly will depend on the exact positions of all the superatoms on the substrate.

I have also studid the adsorption of small silver clusters over stepped graphite surface. Graphite surface is naturally full of point defects, step edges, bends etc. In many experiments, it has been found that the sliver clusters are very mobile on terraces and are significantly larger than those at steps. The reduced diffusion rate along the steps inhibits the growth of larger particles. To understand this phenomenon, we deposited small silver clusters on a stepped graphite surface. Step edges on a graphite surface act as strong attractive sinks for silver adatoms and clusters. The attractive effect of a step extends all the way to 3.5 A on the upper terrace and 6 A on the lower terrace. Some small silver clusters break up as a consequence of the strong Ag-C interaction even at zero temperature. Other clusters also distort to take advantage of the step edge. At finite temperatures (*ab-initio* MD) the clusters diffuse to the step edge and then break up so that ideally each Ag atom can sit at each groove (active site) of an armchair step, and a self-assembled nanowire is formed. Our simulations show that Ag atoms that get bonded to the step edge C atoms do not diffuse significantly even at 600 K. It is the Ag atoms away from the step, bonded to other Ag atoms, that diffuse along the step direction. As the temperature is gradually lowered, dumbbell like structures are formed as seen in experiments. Based on these observations we suggest that by depositing small size- selected Ag clusters on a stepped graphite surface at elevated temperatures (¿ 600 K), and controlling the cluster density to match the available step-edge active sites, it may be possible to fabricate self-assembled atomically thin nano-wires.

Publications:

1. Akansha Singh and Prasenjit Sen, *Finding the right support for magnetic superatom assembly from density functional calculations,* Phys. Rev. B **91**, 035438 (2015).

2. Akansha Singh and Prasenjit Sen, *Density functional study of silver clusters on a stepped graphite surface: Formation of self-assembled nanowires,* Published in PCCP, DOI:10.1039/C5CP01016K.

Preprints:

1. G. Narsinga Rao, R. Shankar, Akansha Singh, I. Panneer Muthuselvam, Viveka Nand Singh, Guang-Yu Guo and F. C. Chou, *Spin dimer and quadrumer of tellurate-bridged copper spins in quantum antiferromagnet* Ba_2CuTeO_6, (In preparation).

2. Sunil K. Karna, C.-W. Wang, R. Sankar, M. Avdeev, Akansha Singh, V. N. Singh, I. P. Muthuselvam, Guang-Yu Guo and F. C. Chou,*Negative thermal expansion and magnetic ordering in double tungstate* $Li_2Ni(WO_4)_2$, (In preparation).

3. Akansha Singh, Chiranjib Majumder and Prasenjit Sen,*CO-oxidation by* α*(0001)-*Al_2O_3 *supported* Ag_nAu_m *(n+m=2-4) clusters : A Density Functional Theory simulations,* (In preparation).

Conference/Workshops Attended:

1. *Materials Simulations Theory and Numerics Summer School,* India, June, 2014.

2. *International Symposium on Clusters and nano-scale Materials,* India, March, 2014.

Visits to other Institutes:

1. National Taiwan University, Taipei, Taiwan, October, 2014

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 established the overall phase diagram in terms of correlation strength, SOC, and temperature. We delineate the metal, semi-metal, and insulator phases, their topological character, the nature of magnetic order and the finite temperature charge dynamics. The results take us forward in establishing a detailed thermal phase diagram of the pyrochlore iridates.

Preprints:

1. Nyayabanta Swain and Pinaki Majumdar, *Mott Transition and Magnetic Correlations on the Frustrated Checkerboard Lattice,* (in preparation).

2. Nyayabanta Swain and Pinaki Majumdar, *The Mott Transition on the Pyrochlore Lattice,* (in preparation).

Conference/Workshops Attended:

1. *Workshop on Current Trends in Frustrated Magnetism*, Jawaharlal Neheru University (JNU), New-Delhi, India (08-13 February, 2015).

Invited Lectures/Seminars:

1. *Mott transition on strongly frustrated lattices*, Poster Presentation at the *Workshop on Current Trends in Frustrated Magnetism*, Jawaharlal Neheru University (JNU), New-Delhi, India (11 and 12 February, 2015).

2. *Mott transition on strongly frustrated lattices*, Poster Presentation at the *School on Topological Quantum Matter*, Harish-Chandra Research Institute, Allahabad, India (17 February, 2015).

3. *Superconductivity; An interesting story of interacting electrons*, Lectures to Class XI-XII children at the Scientific Workshop by the Rajbhasa Committee, Harish-Chandra Research Institute, Allahabad, India (May, 2015).

Saurabh Pradhan

Research Summary:

In the last year I have studied the Hubbard-Holstein Model within classical auxiliary field method. It is important to understand how electron-electron repulsion and electron-phonon interaction compete with each other within this Model. In the strong coupling region of this two interaction system turn out to be insulator. Ground state is either anti-ferromagnetic or charge density wave. There is a first order transition in the parameter space from the one of the state to the other one. Para-magnetic metal phase shows up in the weak coupling region.

Even after enormous effort spend in last few decades origin superconductivity in many material is very less understood. Keeping in mind there are many material turn into superconductor under different conditions, we asked what is the fraction of superconducting sites one need to make a metal to Superconductor. To answer this question we have considered random site diluted negative U Hubbard Model. We have found that there is a critical concentration above which superconductivity starts to appear in the system. We have demonstrated how spectral function, optical conductivity, superconducting order parameter changes as function doping and attraction strength. Bench marking these results we are now trying to understand how this site dilution will effect the a band Insulator.

Preprints:

1. Saurabh Pradhan, Sayan Basak and G. Venkateswara Pai, *Effect of site dilution in The Two-dimensional attractive Hubbard Model* , (in preparation)

2. Saurabh Pradhan and G. Venkateswara Pai, *Holstein-Hubbard model at half filling : a static auxiliary field study,* (in preparation)

3. Udit Khanna, Arijit Kundu, Saurabh Pradhan and Sumathi Rao, *Proximity induced superconductivity in Weyl semi-metals,* Phys. Rev. B 90, 195430 (2014)

Conference/Workshops Attended:

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

Shankha Banerjee

Research Summary:

In the academic year 01.04.2014 to 31.03.2015, I have worked on different aspects of Beyond the Standard Model physics.
In the first part I have looked at the possibility of probing anomalous Higgs couplings at future e^+e^- colliders. Here, the effective operator formalism has been used to see the effects of anomalous Higgs couplings with different Lorentz structures. We showed that the future electron-positron colliders have a good prospect of discriminating such anomalous couplings solely from the total rates of the Higgs production and the ratios from different production modes.
In another work, we discussed the future prospects of heavy neutrino searches at next generation lepton colliders. In particular, we focused on the planned electron-positron colliders, operating in two different beam modes, namely, e^+e^- and e^-e^-. In the e^+e^- beam mode, we considered various production and decay modes of the heavy neutrino (N), and found that the final state with $e + 2j + \not{E}$, arising from the $e^+e^- \to N\nu$ production mode, is the most promising channel. However, since this mode is insensitive to the Majorana nature of the heavy neutrinos, we also studied a new production channel $e^+e^- \to Ne^\pm W^\mp$, which leads to a same-sign dilepton plus four jet final state, thus directly probing the lepton number violation in e^+e^- colliders. In the e^-e^- beam mode, we studied the prospects of the lepton number violating process of $e^-e^- \to W^-W^-$, mediated by a heavy Majorana neutrino. We used both cut-based and multivariate analysis techniques to make a realistic calculation of the relevant signal and background events, including detector effects for a generic linear collider detector. We found that with the cut-based analysis, the light-heavy neutrino mixing parameter $|V_{eN}|^2$ can be probed down to $\sim 10^{-4}$ at 95% C.L. for the heavy neutrino mass up to 400 GeV or so at $\sqrt{s}$ =500 GeV with 100 fb^{-1} of integrated luminosity. For smaller mixing values, we showed that a multivariate analysis can improve the signal significance by up to an order of magnitude. These limits will be at least an order of magnitude better than the current best limits from electroweak precision data, as well as the projected limits from $\sqrt{s}$ =14 TeV LHC.

Publications:

1. Gilad Amar, Shankha Banerjee, Stefan von Buddenbrock, Alan S. Cornell, Tanumoy Mandal, Bruce Mellado, Biswarup Mukhopadhyaya, *Exploration of the Tensor Structure of the Higgs Boson Coupling to Weak Bosons in e^+e Collisions*, JHEP **1502**, 128, (2015)

Preprints:

1. Shankha Banerjee, P. S. Bhupal Dev, Alejandro Ibarra, Tanumoy Mandal, Manimala Mitra, *Prospects of Heavy Neutrino Searches at Future Lepton Colliders,* arXiv:1503.05491 [hep-ph]

Conference/Workshops Attended:

1. *Future Colliders, UK HEP Forum*, United Kingdom, November, 2014,

2. *"LHC and Dark Matter" workshop*, India, February, 2015.

Visits to other Institutes:

1. Bethe Center for Theoretical Physics; Physikalisches Institut, Universität Bonn, Bonn, Germany, October, 2014,

2. Institute for Theoretical Physics; Karlsruher Institut für Technologie, Karlsruhe, Germany, October, 2014,

3. Laboratoire d'Annecy-Le-Vieux de Physique Thèorique, Annecy, France, October, 2014,

4. Laboratoire de Physique Thèorique d'Orsay, Orsay, France, October, 2014,

5. School of Physics and Astronomy, The University of Manchester, Manchester, United Kingdom, November, 2014,

6. Institute for Particle Physics Phenomenology, Durham University, Durham, United Kingdom, November, 2014,

7. Department of Physics, Oxford University, Oxford, United Kingdom, November, 2014,

8. School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom, November, 2014,

9. Institut de Fisica d'Altes Energies, Barcelona, Spain, November, 2014,
10. Indian Institute of Science, Bangalore, India, March, 2015.

Invited Lectures/Seminars:

1. *A Higgs or the Higgs ? A detailed look at anomalous Higgs couplings*,
    - Bethe Center for Theoretical Physics; Physikalisches Institut, Universität Bonn, Bonn, Germany, October, 2014,
    - Institute for Theoretical Physics; Karlsruher Institut für Technologie, Karlsruhe, Germany, October, 2014,
    - Laboratoire d'Annecy-Le-Vieux de Physique Thèorique, Annecy, France, October, 2014,
    - Laboratoire de Physique Thèorique d'Orsay, Orsay, France, October, 2014,
    - School of Physics and Astronomy, The University of Manchester, Manchester, United Kingdom, November, 2014,
    - Institute for Particle Physics Phenomenology, Durham University, Durham, United Kingdom, November, 2014,
    - Department of Physics, Oxford University, Oxford, United Kingdom, November, 2014,
    - School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom, November, 2014,
    - Institut de Fisica d'Altes Energies, Barcelona, Spain, November, 2014,
    - Indian Institute of Science, Bangalore, India, March, 2015.

Abhishek Joshi

Research Summary:

This year we studied superfluid mott transition in the context of Bose Hubbard Model using auxillary field monte carlo techniques.We have calulated structure factor,spatial maps showing thermal evolution of the sytem,spectral function of bosons and condensate depletion as a function of interaction strength and temperature.

Ushoshi Maitra

Research Summary:

A radion in a scenario with a warped extra dimension(Randall-Sundrum model) can be lighter than the Higgs boson, even if the Kaluza-Klein(KK) excitation modes of the graviton turn out to be in the multi-TeV region. The discovery of such a light radion would be gateway to new physics. We showed that the two-photon mode of decay can enable us to probe a radion in the mass range 60 - 110 GeV. We take into account the diphoton background, including fragmentation effects, and include cuts designed to suppress the background to the maximum possible extent. Our conclusion is that, with an integrated luminosity of $3000\mathrm{fb}^{-1}$ or less, the next run of the Large Hadron Collider(LHC) should be able to detect a radion in this mass range, with a significance of 5 standard deviations or more.

Publications:

1. Satyaki Bhattacharya, Mariana Frank, Katri Huitu, Ushoshi Maitra, Biswarup Mukhopadhyaya, Santosh Kumar Rai, *Probing the light radion through diphotons at the Large Hadron Collider*, Phys. Rev. D **91**, 016008, (2015)

Conference/Workshops Attended:

1. *LHCDM*, India, February, 2015.

Visits to other Institutes:

1. Indian Association for Cultivation of Science, Kolkata, India, June, 2014.

2. Brookhaven National Laboratory, NewYork, USA, October 2014.

3. Syracuse University, Syracuse, USA, October 2014.

4. Pittsburgh University, Pennsylvania, USA, October 2014.

5. Michigan State University, East Lansing, Michigan, USA, October 2014.

6. Concordia University, Montreal, Canada, November 2014.

7. Helsinki University, Helsinki, Finland, November-December 2014.
8. Tata Institute of Fundamental Research, Mumbai, India, January 2015.

Aritra Gupta

Research Summary:

The IceCube (IC) has recently reported three ultra-high energy cascade events, with two events being seen at almost the same energy of = 1.1 PeV, and a third one seen at = 2.1 PeV. In addition, they also see events (both cascade and muon-track) at lower energies ranging from 10 - 400 TeV.We explored whether the high energy events can come from some dark matter particles and hence we can get the first direct hints of dark matter in IceCube. If so this would be the first ever direct detection of dark matter in high energies.
In a follow up work we are trying to extend this idea to several possible dark matter models and do phenomenological study.

Publications:

1. Atri Bhattacharya, Raj Gandhi, Aritra Gupta ,*The Direct Detection of Boosted Dark Matter at High Energies and PeV events at IceCube*, JCAP03(2015)027, DOI : 10.1088/1475-7516/2015/03/027 .

Conference/Workshops Attended:

1. *DAE-BRNS HEP Symposium 2014*, IIT GUWAHATI, DECEMBER, 2014.

Utkarsh Mishra

Research Summary:

During the academic year 2014-15, I, under the supervision of Prof. Ujjwal sen, have worked on the dynamics of bipartite and multipartite quantum correlations in many-body complex quantum systems including spin models and biological system such as Fenna-Mathews-Olson complex. I have also worked on detection of quantum phase transitions in spin chains using Benford's law.
We have studied time-evolution of multiparty quantum correlations as quantified by monogamy scores and bipartition collections of quantum correlations in light-harvesting complexes modeled by the fully connected and the Fenna-Mathews-Olson (FMO) networks. The dynamics consists of a coherent term as well as dissipative, dephasing, and sink operator terms. We show that the relative values of the ingredients of multiparty quantum correlation measures in the time dynamics clearly indicate the primary route of energy transfer from the antenna to the bacterial reaction center in the FMO complex
We studied quantum phase transition in XY model using Benfords law. Benfords lawis an empirical law predicting the distribution of the first significant digits of numbers obtained from natural phenomena and mathematical tables. We detect the zero-temperature quantum phase transition and find that our method gives better finite-size scaling exponents for the critical point than many other known scaling exponents using measurable quantities like magnetization, entanglement, and quantum discord. We extend our analysis to the same system but at finite temperature and find that it also detects the finite-temperature phase transition in the model. Moreover, we compare the Benford distribution analysis with the same obtained from the uniform and Poisson distributions. The analysis is furthermore important in that the high-precision detection of the cooperative physical phenomena is possible even from low-precision experimental data.

Publications:

1. Utkarsh Mishra, Aditi Sen(De), and Ujjwal Sen, *Local decoherence-resistant quantum states of large systems,* Phys. Lett. A **379**, 261 (2015).

2. Ameya Deepak Rane, Utkarsh Mishra, Anindya Biswas, Aditi Sen(De), and Ujjwal Sen, *Benford's Law gives better scale exponents in phase transitions of quantum XY models,* Phys. Rev. E **90**, 022144 (2014).

Preprints:

1. Utkarsh Mishra, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Constructive interference between disordered couplings in quantum spin models,* (arXiv:1408.0179 (2014)).

2. Titas Chanda, Utkarsh Mishra, Aditi Sen De, Ujjwal Sen, *Time dynamics of multiparty quantum correlations indicate energy transfer route in light-harvesting complexes,* (arXiv:1412.6519 (2014)).

Visits to other Institutes:

1. University of Salerno, Fisciano, Italy, March 2015.

2. Condensed matter and quantum information theory group, Scuola Normale Superiore, Pisa, Italy, February 2015.

3. Light and Atomic Matter Physics group, Raman Research Institute, Bangalore, India, September 2014.

Invited Lectures/Seminars:

1. *Benfords Law detects quantum phase transitions similarly as earthquakes*, University of Salerno, Fisciano, Italy, March 2015.

2. *Dynamics of quantum correlations in many-particle systems*, University of Salerno, Fisciano, Italy, March 2015.

Maguni Mahakhud

Research Summary:

The tests of the Standard Model (SM) have been going on for several decades in various experiments and most of its predictions have been tested in an unprecedented accuracy. The recent discovery of Higgs boson by ATLAS and CMS collaborations at the Large Hadron Collider (LHC) puts the SM on firm footing. The Higgs boson results from Higgs mechanism that provides a framework for electroweak symmetry breaking. Elementary particles such as leptons, quarks, gauge bosons and Higgs boson acquire masses through the Higgs mechanism. The mass of the Higgs boson being a parameter of the theory can not be predicted by the SM and hence its discovery provides a valuable information on this. Results from Higgs searches at LEP and Tevatron were crucial ingredients to the recent discovery in narrowing down the search regions for the LHC collaborations. The direct searches at the LEP excluded Higgs of mass below 114.4 GeV and the precision electroweak measurements hinted for Higgs boson in the mass less than 152 GeV at 95% confidence level (CL). Tevatron on the other hand excluded Higgs of mass in the range $162 - 166$ GeV at 95% CL.

The dominant production mechanism for the Higgs production at the LHC is gluon gluon fusion through top quark loop. The subdominant ones come from vector boson fusion, associated production of Higgs with vector bosons and top anti-top pairs and bottom anti-bottom annihilation. The inclusive production cross section for the Higgs production is known to an unprecedented accuracy due to many breakthroughs in the computation of amplitudes, loop and phase space integrals. For gluon-gluon , vector boson fusion processes , and associated production with vector bosons , the inclusive rates are known to NNLO accuracy in QCD. There are also studies related to the Higgs production in association with bottom quarks which were also motivated to study Higgs boson in certain SUSY models, namely MSSM. The coupling of bottom quarks become large in the large $\tan\beta$ region, where $\tan\beta$ is the vacuum expectation values of up and down type Higgs fields in the Higgs sector of MSSM. Such large couplings can enhance gluon fusion as well as bottom quark fusion subprocesses. Fully inclusive cross section for Higgs production in association with bottom quark to NNLO level accuracy is also known in the variable flavour scheme (VFS) , while it is known only up to NLO level in the fixed flavour scheme (FFS) . In the VFS, one assumes the initial state bottom quarks inside the proton. They are there as a result of emission of

collinear bottom anti-bottom states from the gluons intrinsically present inside the proton. They being collinear give large logs which need to be resummed. The resummed contribution is the source for non-vanishing bottom and anti-bottom parton distribution functions inside the proton in the VFS scheme.
In the first paper listed below we study one and two loop QCD amplitudes for the process $H \to b + \bar{b} + g$ treating both bottom and other four light quarks massless.
Also in another project using recent full N^3LO threshold corrections for Higgs production,we calculated the full N^3LO threshold corrections for Drell Yan processes in SM.

Publications:

1. Taushif Ahmed,Maguni Mahakhud , Prakash Mathews,Narayan Rana , V. Ravindran, *Two-Loop QCD Corrections to Higgs $\to b + \bar{b} + g$ Amplitude,* JHEP **1408**,075, (2014)

2. Taushif Ahmed,Maguni Mahakhud,Narayan Rana , V. Ravindran, *Drell-Yan production at threshold in N^3LO QCD* Phys. Rev. Lett. 113, 112002 (2014)

Conference/Workshops Attended:

1. *Workshop on LHC and Dark Matter*,Indian Association of Cultivation of Sciences,Kolkata, 23rd-28th February 2015

Visits to other Institutes:

1. Institute of Physics,Bhubaneswar,17th-22nd February 2015

2. Indian Institute of Technology,Mumbai,26th-27th march 2015

Invited Lectures/Seminars:

1. *Next to next to leading order QCD Corrections in Models of TeV Scale Gravity*, HRI, Allahabad,30th July 2014.

2. *Next to next to leading order QCD Corrections in Models of TeV Scale Gravity*, Institute of Physics, Bhubaneswar,18th February 2015.

3. *Next to next to leading order QCD Corrections in Models of TeV Scale Gravity*, IIT Bombay, Mumbai,27th March 2015.

Avijit Misra

Research Summary:

During this academic period I have mainly worked on quantum thermodynamics and its implications in quantum information theory. In particular, how much work one can extract from a athermal quantum state, has been the prime motivation of my study. It has been shown the free energy of the system quantifies the amount of work that one can harness from a quantum state. Moreover, the form of the free energy which is internal energy minus the temperature times entropy, remains unaffected even beyond the equilibrium and is independent of the choice of entropy when the internal energy is defined suitably for the specific entropy. Thus, we arrive at the "form invariance" of thermodynamics when it is considered from the principle of maximum entropy. Further, it is established from a generalized perspective that the *universality* of the Carnot statement of the second law of thermodynamics is a consequence of the form invariance of the free energy.

In addition to this, the role of quantum correlations in the predictive power of a driven quantum system has been studied and it has been explored whether the initial quantum correlations helps the the driven system to be more predictive.

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,* To appear in Phys. Rev. E, arXiv:1406.5065.

Preprints:

1. Avijit Misra, Uttam Singh, Manabendra Nath Bera, A. K. Rajagopal, *From Rényi Relative Entropic Generalization to Quantum Thermodynamical Universality,* (in preparation).

2. Arun K. Pati, Avijit Misra, *Predictive Information for Driven Quantum System,* (in preparation).

Conference/Workshops Attended:

1. *Young Quantum - 2015 (YouQu-2015)* , India, February, 2015.

Visits to other Institutes:

1. Indian Institute of Information Technology, Hyderabad, India, July, 2014.
2. Institute of Physics, Bhuwaneswar, India, December, 2014.

Seminars:

1. *Quantum Correlation with Sandwiched Relative Entropies*, Indian Institute of Information Technology, Hyderabad, India, July, 2014.
2. *Quantum Correlation with Generalized Relative Entropies: Advantageous to Study Quantum Phase Transitions*, Institute of Physics, Bhuwaneswar, India, December, 2014.

Manoj Kumar Mandal

Research Summary:

We present the threshold next-to-next-to-next-to leading order (N^{3}LO) perturbative QCD corrections to the rapidity distributions of dileptons in the Drell-Yan process and Higgs boson in gluon fusion. We also report the rapidity distribution of the Higgs boson produced through bottom quark annihilation and the results of the inclusive cross-section of the associated production of the Higgs boson with vector boson at third order in QCD using the threshold approximation. We provide a framework, based on the factorization properties of the QCD amplitudes along with Sudakov resummation and the renormalization group invariance, that allows one to perform the computation of the threshold corrections in a consistent, systematic and accurate way. We use various state of the art three loop results that have been recently available to obtain these results. For the rapidity distribution of the Higgs boson, we demonstrate numerically the importance of these corrections at the LHC.
For the rapidity distribution of the Higgs boson produced through bottom quark annihilation, the recent results on threshold N^{3}LO correction in QCD for the Drell-Yan production and on three loop QCD correction to Higgs form factor with bottom anti-bottom quark are used to achieve this task. We also demonstrate the numerical impact of these corrections at the LHC.
For the associated production of Higgs boson with vector boson computed at threshold N^{3}LO in QCD we use the recently available result of the threshold contributions to the inclusive Drell-Yan production cross-section at third order in the strong coupling constant. We have implemented it in the publicly available computer package vh@nnlo, thereby obtaining the numerical impact of threshold N^{3}LO contributions for the first time. We find that the inclusion of such corrections do reduce theoretical uncertainties resulting from the renormalization scale.

Publications:

1. Taushif Ahmed, M. K. Mandal, Narayan Rana and V. Ravindran, *Rapidity Distributions in Drell-Yan and Higgs Productions at Threshold to Third Order in QCD,* Phys. Rev. Lett. **212003**, 113, (2014)

2. Taushif Ahmed, M. K. Mandal, Narayan Rana, V. Ravindran, *Higgs Rapidity Distribution in $b\bar{b}$ Annihilation at Threshold in N^{3}LO QCD*, JHEP

131, 1502, (2015)

3. M. C. Kumar, M. K. Mandal, V. Ravindran, *Associated production of Higgs boson with vector boson at threshold N^3LO in QCD*, JHEP **037**, 1503, (2015)

Conference/Workshops Attended:

1. *International Workshop on Frontiers of QCD*, INDIA, December, 2014.
2. *LHCDM-2015*, INDIA, February, 2015.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, November, 2014
2. Institute of Physics, Bhubaneswar, India, February, 2015
3. Indian Institute of Technology, Bombay, India, March, 2015

Invited Lectures/Seminars:

1. *Rapidity distribution in Higgs production at threshold to third order in QCD*, International Workshop on Frontiers of QCD, IIT, Mumbai, December, 2014.

Swapnamay Mondal

Research Summary:

A) I have mainly worked on Black Hole microstate counting under the guidance of Prof. Ashoke Sen. Exact results for the BPS index are known for a class of BPS dyons in type II string theory compactified on a six dimensional torus. We have set up the problem of counting the same BPS states in a duality frame in which the states carry only Ramond-Ramond charges. We have explicitly counted the number of states carrying the lowest possible charges and found agreement with the result obtained in other duality frames. Furthermore, we found that after factoring out the supermultiplet structure, each of these states carry zero angular momentum. This is in agreement with the prediction obtained from a representation of these states as supersymmetric black holes. This work has been done Under the guidance of Prof. Ashoke Sen and in collaboration with Abhishek Chowdhury and Richard Garavuso and published in JHEP as JHEP 10(2014)186 [arXiv:1405.0412].

B) We have further been working towards explicit counting for higher charges. To do this essentially we have to count number of solutions of a collection of polynomial equations which are further subject to complex gauge identification.

C) We are also exploring similar questions for $N = 4$ theory as well, which can be obtained by K3 compactification. We proceed by thinking of K3 being obtained by blowing up Z_2 orbifold of 4 torus.

D) In another work I have proposed a measure for entanglement of pure states of indistinguishable particles. Entanglement is well understood concept for distinguishable particles. However fundamental particles are inherently indistinguishable and when they occupy orthogonal modes, i.e. have orthogonal wave functions, they are effectively distinguishable. Thus there should exist a formulation for entanglement which works in the generic case, i.e. even when wave functions overlap. To achieve this, I have considered Rènyi entropies which are measurable quantities. Outcomes of such measurements for a generic case are conjectured in terms of Rènyi entropies of spatial regions in a field theory. To leading order naive quantum mechanical answers are reproduced. Corrections depend on overlap of wave functions and exhibit novel features. In a generic case the Von Neumann entropy computed from these Rènyi entropies has been argued to be a measure of entanglement of pure states and a formula for this has been conjectured in terms of Von Neumann entropies of spatial regions in field theory. It seems, due to the corrections it is possible for the entanglement to exceed maximal quantum mechanical value, e.g. log2 for a single qubit. This work can be found in arXiv with the following number arXiv:1501.01743.

Publications:

1. Abhishek Chowdhury, Richard Garavuso, Swapnamay Mondal, Ashoke Sen, *BPS state counting in N=8 supersymmetric string theory for pure D-brane configurations,* JHEP **10**, 186, (2014)

Preprints:

1. Abhishek Chowdhury, Richard Garavuso, Swapnamay Mondal, Ashoke Sen, *BPS state counting in N=8 supersymmetric string theory for pure D-brane configurations,* 1405.0412

2. Swapnamay Mondal, *A unified formulation for entanglement of distinguishable and indistinguishable particles,* 1501.01743

Conference/Workshops Attended:

1. *Indian Strings Meet*, India, December, 2014

2. *Spring school on Superstring theory and related topics*, Italy, March-April, 2015.

Visits to other Institutes:

1. SINP, Kolkata, India, June 2014.

2. ICTP, Trieste, Italy, March-April 2015.

3. SISSA, Trieste, Italy, March 2015.

4. ICFO, Barcelona, Spain, April 2015.

5. CERN, Geneva, Switzerland, April 2015.

Other Activities:

1. I teach school kids from nearby village in a school, organized by HARSHA, a HRI students initiative.

Roji Pius

Research Summary:

With Ashoke Sen and Arnab Rudra we used off-shell formulation of string perturbation theory to study the string theory around dynamically shifted vacuum. In other unfinished project we are trying to use off-shell amplitudes with this prescription to compute two loop mass renormalisation of non-BPS SO(32) spinor of SO(32) heterotic string theory. This will be the first ever 2 loop computation involving massive external states in string theory.

Publications:

1. R. Pius, A. Rudra, A. Sen, *String Perturbation Theory Around Dynamically Shifted Vacuum.* JHEP 1410, 070 (2014)
2. R. Pius, A. Rudra, A. Sen, *Mass Renormalization in String Theory: General States.* JHEP 1407, 062 (2014).
3. R. Pius, A. Rudra, A. Sen, *Mass Renormalization in String Theory: Special States.* JHEP 1407, 058 (2014).
4. R. Pius, A. Sen, *S-duality Improved Perturbation Theory in Compactified Type I / Heterotic String Theory.* JHEP 1406, 068 (2014).

Conference/Workshops Attended:

1. *Strings 2014*, USA, June 2014.
2. *PiTP 2014*, USA, June 2014.

Visits to other Institutes:

1. KITP, UCSB, Santa-Barbara, USA, June 2014.
2. Caltech, Pasadena, USA, June 2014.
3. IAS Princeton, USA, June 2014.
4. ETH-ITS, Zurich, Switzerland, November 2014.
5. MIT, Boston, USA, December 2014.

Invited Lectures/Seminars:

1. *Scattering amplitudes in string theory*, Talks in theoretical sciences 2014, ETH-ITS, Zurich, Switzerland, November 2014.

2. *Off-shell string theory*, Gong Show: PiTP 2014, IAS Princeton, New Jersey, USA, June 2014.

3. *Off-shell string theory*, HEP Seminar Caltech, Pasadena, USA, June 2014.

4. *Off-shell string theory*, HEP Seminar, KITP, Santa Barbara, USA, June 2014.

Academic recognition/Awards:

1. **Pappalardo Fellowship,** MIT, USA, 2015-2018 (Finalist, Alternate)

2. **Junior Fellowship,** ETH-Institute of Theoretical Sciences, Switzerland, 2015-2018

Other Activities:

1. Semester long lecture series : *Supergeometric formulation of perturbative superstring theory.* HRI Allahabad, India, August - November, 2014.

Udit Khanna

Research Summary:

In the previous year, I continued the work on proximity effect of an s-wave superconductor on the surface states of a weyl semimetal. The tunnelling of electrons between the surface of the semimetal and the superconductor can lead to a small pairing amplitude at the surface of the semimetal. I studied the details of this pairing amplitude by computing the normal and anomalous parts of the green's function in the semimetal. The induced pairing has both s and p wave pairings due to the large spin orbit coupling. I also studied the effect of multiple orbitals and found that both intra-orbital and inter-orbital pairings can be induced depending on the various parameters of the theory. This work was in collaboration with Arijit Kundu, Saurabh Pradhan and Sumathi Rao.

Currently I am working with Dibyakanti Mukherjee, Arijit Kundu and Sumathi Rao to study the SNS junctions of weyl semimetals. The aim of the study is to look at the spectrum of Andreev bound states and the Josephson current through such devices.

I am also working on the transport properties of quantum hall states in constricted geometries. Interactions between electrons can lead to magnetism in quantum hall states at odd filling factors, which in turn affects the charge transport properties of these systems. I am currently studying the properties of the ground and excited states at odd fillings through a self consistent hartree fock method at zero temperature. The aim is to understand the low energy excitations and how they change as the geometry of the hall bar is changed. This project is in collaboration with Yuval Gefen, Ganpathy Murthy and Sumathi Rao.

Publications:

1. Udit Khanna, Arijit Kundu, Saurabh Pradhan and Sumathi Rao, *Proximity induced superconductivity in Weyl Semimetals,* Phys. Rev. B **90**, 195430, (2014)

Conference/Workshops Attended:

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

Abhishek Chowdhury

Research Summary:

Exact results for the BPS index are known for a class of BPS dyons in type II string theory compactified on a six dimensional torus. In the first paper we set up the problem of counting the same BPS states in a duality frame in which the states carry only Ramond-Ramond charges. We explicitly count the number of states carrying the lowest possible charges and find agreement with the result obtained in other duality frames. Furthermore, we find that after factoring out the supermultiplet structure, each of these states carry zero angular momentum. This is in agreement with the prediction obtained from a representation of these states as supersymmetric black holes.

In the second paper we compute logarithmic corrections to the twisted index B_6^g in four-dimensional $\mathcal{N} = 4$ and $\mathcal{N} = 8$ string theories using the framework of the Quantum Entropy Function. We find that these vanish, matching perfectly with the large–charge expansion of the corresponding microscopic expressions.

Publications:

1. Abhishek Chowdhury, Richard S. Garavuso, Swapnamay Mondal, Ashoke Sen, *BPS State Counting in N=8 Supersymmetric String Theory for Pure D-brane Configurations*, JHEP **10**, 186, (2014)

2. Abhishek Chowdhury, Rajesh Kumar Gupta, Shailesh Lal, Milind Shyani, Somyadip Thakur, *Logarithmic Corrections to Twisted Indices from the Quantum Entropy Function*, JHEP **11**, 002, (2014)

Conference/Workshops Attended:

1. *Spring School in Superstring and Related topics*, Italy, March 2015.

Visits to other Institutes:

1. IPM, Tehran, Iran, June-July 2014

Satadal Datta

Research Summary:

I joined the astrophysics group as a Ph.D. student in late 2014. I studied self gravitating spherically symmetric accretion of test fluid on compact objects. Then I started working on Newtonian and post Newtonian pseudo-Schwarzschild spherical accretion *including* the self gravity of the flow, as suggested by my supervisor. We focussed on steady state behaviour of the fluid and obtained the respective stationary transonic integral solutions for such flow. To accomplish such task, I developed a novel iterative technique to get more insight into the problem.

Preprints:

1. Satadal Datta and Dhruv Pathak, *Spherically Symmetric Accretion with Self-gravity,*(in preparation)

Asutosh Kumar

Research Summary:

Monogamy is a nonclassical property that limits the amount of quantum correlation that can be shared among different parties in a multiparty quantum system. We prove that monogamy of a convex quantum correlation measure for an arbitrary multipartite pure quantum state leads to its monogamy for the mixed state in the same Hilbert space. In particular, we prove that the square of negativity is monogamous for n-qubit mixed state. Several derived monogamy relations are also discussed. We establish that a general quantum correlation obeys a set of monogamy relations. In a related project, 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.

Distilling highly entangled quantum states from weaker ones is a process that is crucial for efficient and long-distance quantum communication, and has implications for several other quantum information protocols. We introduce the notion of distillation under limited resources, and specifically focus on the energy constraint. The corresponding protocol, which we call the canonical distillation of entanglement, naturally leads to the set of canonically distillable states. We show that for non-interacting Hamiltonians, almost no states are canonically distillable, while the situation can be drastically different for interacting ones. Several paradigmatic Hamiltonians are considered for bipartite as well as multipartite canonical distillability. The results have potential applications for practical quantum communication devices.

Mutual information is the reciprocal information that is common to or shared by two or more parties. Quantum mutual information (QMI) for bipartite quantum systems is non-negative, and bears the interpretation of total correlation between the two subsystems.This is, however, not true for three or more party quantum systems. Multiparty QMI can be negative. That QMI can assume negative value is confronting, and we give operational definition of QMI which is non-negative. In multiparty quantum discord, we observe that quantum discord increases when measurement is performed on larger number of subsystems. Consequently, the symmetric version of quantum discord, which involves measurement on all parties, reveals the maximal quantumness. This suggests that the measured mutual information should not be interpreted as classical correlation.

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. For the sender(Alice)-receiver(Bob)-eavesdropper(Eve) trio, monogamy of quantum correlations ensures that if Alice and Bob are sufficiently correlated then Alice (or Bob) and Eve are less correlated, i.e., the adversary Eve is essentially factorized out. Consequently, information can be communicated securely. We obtain complementarity relations between purity and various quantum correlations, and show that the upper bound depends on the dimensions of sender-receiver and eavesdropper. We analyze the possibility whether these complementarity relations guarantee secure QKD.

In another project we study the decoherence effects on three-qubit pure states, under global and local noises, using monogamy as the quantum correlation measure. We find that quantum channels can be conclusively identified via monogamy of quantum discord, a information-theoretic quantum correlation measure.

Preprints:

1. Asutosh Kumar, *A Unified Approach Towards Monogamy of Quantum Correlations,* arXiv:1409.8632 [quant-ph].

2. Tamoghna Das, Asutosh Kumar, Amit Kumar Pal, Namrata Shukla, Aditi Sen (De), Ujjwal Sen, *Canonical Distillation of Entanglement,* arXiv:1411.7936 [quant-ph].

3. Asutosh Kumar, *Multiparty Operational Quantum Mutual Information,* arXiv:1504.07176 [quant-ph].

4. Asutosh Kumar, Himadri Shekhar Dhar, R. Prabhu, Aditi Sen (De), Ujjwal Sen, *Multiparty Entanglement Bound on Monogamy Scores of Quantum Correlations,* (in preparation).

5. Anindita Bera, Asutosh Kumar, Debraj Rakshit, R. Prabhu, Aditi Sen (De), Ujjwal Sen, *Information-theoretic Complementarity Relations and Quantum Cryptography,* (in preparation).

6. Asutosh Kumar, R. Prabhu, Aditi Sen (De), Ujjwal Sen, *Conclusive Identification of Quantum Channels via Monogamy of Quantum Correlations,* (in preparation).

Conference/Workshops Attended:

1. *Young Quantum-2015 (YouQu-15)*, HRI, India, February 2015.
   Delivered a talk on "Almost All Multipartite States are Monogamous".

Other Activities:

1. Member of local organizing committee of *Young Quantum (YouQu-15)*, Harish-Chandra Research Institute, February 2015.

2. Tutoring Hindi for non-Hindi speaking students on campus.

Debasis Mondal

Research Summary::

During the period April 2014-March 2015, I worked on the "Generalized Fubini-Study Metric and Fisher Information Metric". In this paper, We provide an experimentally measurable local gauge U(1) invariant Fubini-Study (FS) metric for mixed states. Like the FS metric for pure states, it also captures only the quantum part of the uncertainty in the evolution Hamiltonian. We show that this satisfies the quantum Cramer-Rao bound and thus arrive at a more general and measurable bound. Upon imposing the monotonicity condition, it reduces to the square-root derivative quantum Fisher Information. We show that on the Fisher information metric space dynamical phase is zero. A relation between square root derivative and logarithmic derivative is formulated such that both give the same Fisher information. We generalize the Fubini-Study metric for mixed states further and arrive at a set of Fubini-Study metric—called α metric. This newly defined α metric also satisfies the Cramer-Rao bound. Again by imposing the monotonicity condition on this metric, we derive the monotone α metric. It reduces to the Fisher information metric for $\alpha = 1$.

I also focused to apply this newly defined experimentally realizable metric in other aspects of quantum information theory.

Future Plans:

Presently, I'm focusing on the relation between the quantum speed limit and the quantum correlation of the state. I'm also trying to find out the effects of relativity (inertial frame) or gravity (non-inertial frame) on the quantum information.

Papers/Preprints:

1. Debasis Mondal, *Generalized Fubini-Study Metric and Fisher Information Metric,* arXiv:1503.04146 [quant-ph]

2. Debasis Mondal and Arun Kumar Pati, *Quantum Speed Limit in Non-inertial Frame or General Relativistic Scenario,* (in preparation)

Tutorship:

I tutored the course on Classical Electrodynamics during Aug-Dec, 2014. Presently, I'm tutoring the Quantum Information course taken by Prof. Arun K. Pati in this semester (Jan-May, 2015).

Other activities:

Conferences

1. Attended a mini conference "One Day With Quantum Information" on 13^{th} November, 2014.
2. Member of local organizing committee of *Young Quantum - 2015*, Harish-Chandra Research Institute, February 2015.
3. Presented a poster at *Young Quantum - 2015* organized by Harish-Chandra Research Institute, February 2015.
4. Attended *Physics and Applied Mathematics Researchers' Meet - 2015*, Indian Statistical Institute, Kolkata, March 2015.

Invited talks

1. Presented a talk on **Generalized Fubini-Study Metric and Fisher Information Metric**, at *Physics and Applied Mathematics Researchers' Meet - 2015*, Indian Statistical Institute, Kolkata, March 2015.

Nabarun Chakrabarty

Research Summary:

In one project, I studied the inert doublet model and its validity upto high scales under renormalisation group evolution. This model stands successful in addressing the issue of Dark Matter. Moreover, we augmented the scenario by adding right-handed neutrinos with an intent to predict the experimentally observed neutrino mass. Thus, we identified parameter spaces in the model which can account for high scale validity, Dark Matter and correct neutrino mass simultaneously.

A slightly modified spectrum of the Minimal Supersymmetric Standard Model (MSSM), with the left-handed sneutrino at the bottom of the spectrum advocates for a sneutrino Dark Matter. While the Dark Matter phenomenology of such a spectrum has been studied in the past, we sought to look for novel collider signatures. The same sign trilepton signal emerged as one of such signals which would probably enable us to discern such a modified MSSM spectrum at the LHC.

Publications:

1. Nabarun Chakrabarty, Ujjal Kumar Dey, Biswarup Mukhopadhyaya, *High-scale validity of a two-Higgs doublet scenario: a study including LHC data,* JHEP12(2014)166

2. Nabarun Chakrabarty, Tao Han, Zhen Liu, Biswarup Mukhopadhyaya, *Radiative Return for Heavy Higgs Boson at a Muon Collider,* Phys. Rev. D 91, 015008 (2015)

Preprints:

1. Nabarun Chakrabarty, Arindam Chatterjee, Biswarup Mukhopadhyaya, *Same-sign tri-leptons with a left-sneutrino as the lightest minimal supersymmetric particle,* arXiv:1411.7226

2. Nabarun Chakrabarty, Dilip Kumar Ghosh, Biswarup Mukhopadhyaya, Ipsita Saha, *Dark matter, neutrino masses and high scale validity of an inert Higgs doublet model,* arXiv:1501.03700

Conference/Workshops Attended:

1. *XXI DAE-BRNS High Energy Physics Symposium 2014*, IITG, Guwahati, India, December, 2014,

2. *Three Week Workshop on LHC and Dark Matter (LHCDM)*, IACS, Kolkata, India, February, 2015.

Visits to other Institutes:

1. IACS, Kolkata, India, June - July, 2014,

2. IACS, Kolkata, India, September, 2014.

Invited Lectures/Seminars:

1. *Dark matter and neutrino mass in context of an Inert Doublet Model* , XXI DAE-BRNS High Energy Physics Symposium 2014, IITG, Guwahati, India, December, 2014.

Ajanta Maity

Research Summary:

In the past one year, we have studied the properties of monolayer phosphorene and metal interfaces. In this study Schottky barrier height (SBH) at metal-semiconductor (m-s) interface has been calculated. To calculate the SBH we have used two methods, 1) ab-initio, 2) Schottky-Mott rule (this is a semi-empirical method). Using ab-initio method tunneling barrier height between metal and semiconductor has been calculated. Also, the charge density distribution at the interface has been observed. To know the barrier height using Schottky-Mott rule, the work function of metal and electron affinity of semiconductor has been calculated. The barrier height has been found out by bond rearrangement and amount of charge transfer between metal and semiconductor.

To do these calculations Palladium (Pd), Nickel(Ni), Gold(Au) and Titanium(Ti) were selected. All these metal surfaces are bulk terminated. As the SBH depends on the work function of metal and work function is a surface property therefore different metal surfaces are taken. (100), (110), (111) surfaces for Pd, (100),(110) surfaces for Ni, (110) surface for Au, and (0001) surface for Ti are taken. The

All the calculations has been done using VASP (Vienna Ab-initio Simulation Package). To check which exchange-correlation functional among LDA, GGA-PBE, GGA-PBE+vdW-DF2 correction and GGA-PBE+ Grimme correction will give better binding between metal and phosphorene some test calculations has been done. In this calculation one metal atom of each type is taken and put it on phosphorene slab. From our study we conclude that GGA-PBE gives better binding energy of one atom-Phosphorene slab with less affect in the phosphorene slab. Therefore all the metal-phosphorene, calculation has been done with GGA-PBE exchange-correlation.

Conference/Workshops Attended:

1. School on topological quantum matter, HRI, India, February, 2015

Aditya Banerjee

Research Summary:

In the academic year 2013-2014, I have worked in the area of fractional quantum Hall effect in condensed matter physics. The problems that I have worked on are concerned with analytically studying some bilayer and multilayer fractional quantum Hall systems in the present of inter-layer couplings that are neither weak nor strong. The primary approach of theoretical analysis has been the so-called parton construction of FQH systems and thereby using the properties of the emergent gauge degrees of freedom and their coupling with matter fields to derive some universal properties, and if possible also qualitative phase diagrams, of the resulting new states. A more particular problem in this direction that I have worked on involves trying to generate some kind of a three-dimensional analog of FQH effect (which is intrinsically two-dimensional) starting from a large multilayer structure of 2D FQH systems each coupled intermediately with each other. Such a 3D analog of FQH effect may be relevant for proposing analytical models of strongly interacting 3D fractional topological insulators. This work follows a work done by other authors some years ago, and I have studied and generated a "composite Fermi liquid" analog for these 3D states, which by itself can additionally be a playground for non-Fermi liquid physics in a 3D system which by itself is not so usual. Extension of these works to the non-Abelian case of the pfaffian states has also been considered, although exact results in this problem have not been arrived at yet.

Preprints:

1. Aditya Banerjee, *A composite Fermi liquid like state in three dimensions and its non-Fermi liquid behaviour,* (in preparation)

Conference/Workshops Attended:

1. *School in Topological Quantum Matter*, HRI, India, Ferbruary, 2015

Uttam Singh

Research Summary:

During the academic year 2014-15, our research provided a protocol for experimentally measuring the expectation value of any non-Hermitian operator, which can, in general, be complex, using quantum weak values. In particular, the average of a non-Hermitian operator in a pure state is a complex multiple of the weak value of the positive semi-definite part of the non-Hermitian operator. We also prove a new uncertainty relation for any two non-Hermitian operators and show that the fidelity of a quantum state under quantum channel can be measured using the average of the corresponding Kraus operators. The importance of our method is shown in testing the stronger uncertainty relation, verifying the Ramanujan's formula for sum of square roots of first s natural numbers and in measuring the product of non commuting projectors.

Furthermore, we have provided a mathematically rigorous and operationally clear connection between the two resource theories, namely, the resource theory of quantum coherence and the resource theory of quantum entanglement. Using this connection, we have provided a family of coherence monotones corresponding to entanglement monotones. Also, we have found a trade-off relation between coherence and mixedness of any quantum system. Particularly, we have found a complementarity relation between the maximal coherence and mixedness for a specific class of states, the maximally coherent mixed states (MCMS).

Preprints:

1. Arun Kumar Pati, Uttam Singh and Urbasi Sinha, *Quantum Theory Allows Measurement of Non-Hermitian Operators,* arXiv:1406.3007 .

2. Alexander Streltsov, Uttam Singh, Himadri Shekhar Dhar, Manabendra Nath Bera, and Gerardo Adesso, *Measuring Quantum Coherence with Entanglement,* arXiv:1502.05876 .

3. Uttam Singh, Manabendra Nath Bera, Himadri Shekhar Dhar, and Arun Kumar Pati, *Maximally coherent mixed states: Complementarity between maximal coherence and mixedness,* arXiv:1503.06303 .

Conference/Workshops Attended:

1. *Young Quantum - 2015 (YouQu-2015)* , India, February, 2015.

Visits to other Institutes:

1. Raman Research Institute, Bangalore, India, August 2014,

Invited Lectures/Seminars:

1. *Quantifying quantum coherence via entanglement*, Short Talk, Harish-Chandra Research Institute, Allahabad, India, February 2015.

Academic recognition/Awards:

- Edushine, 2014.

Krashna Mohan Tripathi

Research Summary:

My work, this year, has focussed on the signature of Mazorana zero modes (MZM) in topological superconductors. In particular I have been studying charge transport in heterostructure consisting of single normal metal and one-dimensional topological superconductor where continuum kitaev model and edge states of two-dimensional topological insulator in proximity with ordinary s-wave superconductor are taken as prototypical models of topological superconductor. My current interest aims at generalizing this study to the case of heterostructure consisting of multiple normal metal and topological superconductor.

Conference/Workshops Attended:

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

Subhroneel Chakrabarti

Research Summary:

Since last year I've worked on String Field Theory (SFT) under the guidance of Prof.S.Naik. Recently an extended form of the Berkovits formulation of SFT was used to correctly calculate tree level amplitudes which included the R-sector. However such extension posits a problem if one wishes to go beyond tree level calculation. We have modified the extension which promises a more systematic way of quantizing using BV quantization and subsequently compute loop amplitudes including R-sector. At present we're systematically quantizing the theory.

Conference/Workshops Attended:

1. *Advanced String School*, India, September 2014
2. *Indian Strings Meet*, India, December 2014.

Other Activities:

1. Tutored for the course - General Theory of Relativity (GTR),offered during the monsoon semester, August-December 2014. The instructor was Prof. Ashoke Sen.

Tamoghna Das

Research Summary:

Until now it was an well established fact, that bipartite entanglement is an essential ingredient for a vast majority of known quantum communication schemes, involving two parties. Specifically, it has been established that in the case of pure bipartite states, the capacity of classical information transmission via quantum states increases with the increase of any quantum correlation measure. In a work, we have connected multipartite communication protocols with multiparty quantum correlation measures. In particular, we establish a relation between the capacity of multipartite dense coding and multipartite quantum correlation measures of arbitrary multiqubit states. This correspondence is illustrated both in the case of noiseless and noisy channels for arbitrary shared states. Specifically, we show that in the case of the noiseless quantum channel, if the capacity of classical information transmission using the generalized Greenberger-Horne-Zeilinger (gGHZ) state is the same as that of any multiqubit pure state, then the multipartite quantum correlation of the gGHZ state is either the same or higher than that of the latter states. The result is generic in the sense that it does not rely on the choice of the quantum correlation measure, and is independent of the number of parties. We show that the presence of noise can invert the relative capability of information transfer for two states with the same multiparty quantum correlation content. In particular, we find that the effect of both correlated and uncorrelated covariant noise with respect to the capability of classical information transfer is less pronounced on the gGHZ state as compared to a generic pure multiparty state. We also investigate the effect of noisy channels for the distributed quantum dense coding protocol between several senders and two receivers. The receivers are allowed to perform local (quantum) operations and classical communication (LOCC), and we term the communication protocol as the LOCC-DC protocol and the corresponding capacity as the LOCC-DC capacity. We begin by finding an upper bound on the capacity for arbitrary noisy channels between the senders and the receivers. A tighter bound in closed form is obtained for the case of covariant channels. We also noticed the same inversion of capacity of information transfer for any arbitrary state and gGHZ state with the same multiparty quantum correlation content.

In another work, we have considered the distillation protocol of highly entangled quantum states from weaker ones is a process that is crucial for efficient and long-distance quantum communication. We introduce the notion of distillation under limited resources, and specifically focus on the energy constraint. The corresponding protocol, which we call the canonical distillation of entanglement, naturally leads to the set of canonically distillable states. We show that for non-interacting Hamiltonians, almost no states are canonically distillable, while the situation can be drastically different for interacting ones. Several paradigmatic Hamiltonians are considered for bipartite as well as multipartite canonical distillability. The results have potential applications for practical quantum communication devices.

Publications:

1. Tamoghna Das, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Multipartite Dense Coding vs. Quantum Correlation: Noise Inverts Relative Capability of Information Transfer,* Phys. Rev. A **90**, 022319, (2014)

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, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Distributed quantum dense coding with two receivers in noisy environments,* arXiv:1412.6247
3. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, Ujjwal Sen, *Reducing Computational Complexity of Quantum Correlations,* arXiv:1504.04727

Conference/Workshops Attended:

1. *Young Quantum*, India, February, 2015.

Visits to other Institutes:

1. Bose institute, Kolkata, India, 2015,

Other Activities:

1. Served as a Tutor, Classical Mechanics course, Aug-Dec Semester, 2014.

Debasis Sadhukhan

Research Summary:

During the past year, I mainly worked on the disordered quantum systems where I investigated the behavior of quantum correlations in such systems.
Diverse no-go theorems exist, ranging from no-cloning to monogamies of quantum correlations and Bell inequality violations, which restrict the processing of information in the quantum world. In a multipartite scenario, monogamy of Bell inequality violation and the exclusion principle of dense coding are such theorems which impede the ability of the system to have quantum advantage between all its parts. In ordered spin systems, the twin restrictions of translation invariance and monogamy of quantum correlations, in general, enforce the bipartite states to be neither Bell inequality violating nor dense codeable. We show that it is possible to conquer these constraints imposed by quantum mechanics in ordered systems by introducing quenched impurities in the system while still retaining translation invariance at the physically relevant level of disorder-averaged observables.

We investigate the behavior of quantum correlation of quenched disordered quantum spin models, viz., the XY spin glass and random-field XY models. We show that quenched averaged quantum correlations can exhibit the order-from-disorder phenomenon for finite-size systems as well as in the thermodynamic limit. Moreover, we find that the order-from-disorder can get more pronounced in the presence of temperature by suitable tuning of the system parameters. The effects are found for entanglement measures as well as for information-theoretic quantum correlation ones, although the former show them more prominently. We also observe that the equivalence between the quenched averages and their self-averaged cousins – for classical and quantum correlations – is related to the quantum critical point in the corresponding ordered system.

The length of classical correlators typically decays exponentially and polynomially for the gapped and the gapless ordered quantum spin systems respectively, at zero-temperature. In such systems, quantum entanglement decays exponentially even at the quantum critical point. However, Quantum discord, an information-theoretic quantum correlation measure, behaves like classical correlator. We have investigated the effects of quenched disorder on quantum correlation lengths, viz., entanglement and quantum discord, in the anisotropic XY and XYZ spin chains. We found that there is neither reduction nor enhancement in entanglement length while quantum discord length increases significantly in such systems.

In this project, We address 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. We provide a mathematical description of determining the quantum correlation measure using a restricted set of local measurements. 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. 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. 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.

Publications:

1. 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)

Preprints:

1. Debasis Sadhukhan, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Quantum correlations in quenched disordered spin model: Enhanced order from disorder by thermal fluctuations,* arXiv:1412.8385

2. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, R. Prabhu, Aditi Sen(De), Ujjwal Sen, *Enhancement of Quantum Correlation Length in Quenched Disordered Spin Chains,* arXiv:1503.04770

3. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, Ujjwal Sen, *Reducing Computational Complexity of Quantum Correlations,* arXiv:1504.04727

Conference/Workshops Attended:

1. *One day QIC workshop* , HRI, India, November 2014.

2. *School & Discussion Meeting on Frontiers in Light-Matter Interactions*, IACS, India, December 2014.

3. *School on Topological Quantum Matter*, HRI, India, February, 2015.

4. *Young Quantum-2015 (YouQu-15)*, HRI, India, February 2015.

Other Activities:

1. Member of local organizing committee of *Young Quantum (YouQu-15)*, Harish-Chandra Research Institute, February 2015.

Jyotiranjan Beuria

Research Summary:

During this academic year (April 2014 to March 2015), I along with my collaborators, am studying the viability of having two relatively light top squarks ('stops') in the framework of the Next-to-Minimal Supersymmetric Standard Model (NMSSM). Such light top squarks not only render the NMSSM rather 'natural' but are also allowed by the relevant direct searches at the Large Hadron Collider (LHC) and are shown 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 propose dedicated searches for such light top squarks 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 top squarks may give rise to final states which are not so typical in the search for top squarks.

In another on-going project we are studying the production cross sections in the general case of non-degenerate masses for Level-1 Kaluza-Klein gluon and quarks within the framework of Minimal Universal Extra Dimension (MUED).

Preprints:

1. Jyotiranjan Beuria, Arindam Chatterjee, AseshKrishna Datta and Santosh Kumar Rai, *Two Light Stops in the NMSSM and the LHC,* HRI-P-15-05-001, RECAPP-HRI-2015-007

2. AseshKrishna Datta, Jyotiranjan Beuria, Dipsikha Debnath and Konstantin T. Matchev, *Production cross sections in the Minimal Universal Extra Dimension: The general case of non-degenerate masses for level-1 Kaluza-Klein gluon and quarks* (in preparation)

Conference/Workshops Attended:

1. *MC4BSM-14*, South Korea, May 2014

Kasinath Das

Research Summary:

In the last one year I have been working on one loop QCD corrections to the production of resonant vector diquarks.Diquarks are particles which belongs to color representation of antitriplet or sextet with two color indices .They couple to a pair of quarks or anti-quarks. This work also particularly includes production of diquark with charge +1/3 from a channel containing third generation quarks.This type of scenarios have been considered for the upcoming 13 TeV LHC run.

Conference/Workshops Attended:

1. *XXIX SERC Main School in THEP 2014*, India, December 2014
2. *Workshop on LHC and Dark Matter(LHCDM-2015)*, India, February 2015.

Sauri Bhattacharyya

Research Summary:

I'm currently investigating the impact of small amplitude quantum fluctuations on the finite-T phase diagram of electron-phonon systems under the guidance of Prof. Pinaki Majumdar. The system under study is the Holstein Model. Our goal is to retain all spatial fluctuations of the relevant order parameter at the classical level and to introduce quantum corrections on top of this background. Presently, the focus is on understanding the small-polaron crossover in lattice systems and the associated metal-insulator transition. The method itself is supposed to improve the existing Static Auxiliary Field Monte Carlo scheme, and hence can be adapted to study Mott systems or superconductivity in the future.

Conference/Workshops Attended:

1. *Bangalore School on Statistical Physics - V , India, April, 2014.*
2. *School on Topological Quantum Matter, India, February, 2015.*

Other Activities:

1. Tutored for the course 'Condensed Matter Physics 1', instructed by Dr. G. Venketeswara Pai (Aug-Dec, 2014).

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 using CP(Charge Parity)-odd dimension six gauge invariant operators. In a model independent study of new physics beyond the standard model, we have considered the effect of dimension six CP-odd gauge-Higgs operators on various observables. We analyse five such operators and study constraints on the coupling parameters of these operators coming from the low energy experiments, namely, precision electroweak measurements and the latest experimental bounds on electron and neutron electric dipole moments(EDMs). We also perform a global fit of the LHC data, considering deviations in various production and decay channels of the Higgs boson in presence of anomalous CP-odd vertices.

Preprints:

1. Siddharth Dwivedi, Dilip Ghosh, Biswarup Mukhopadhyay, Ambresh Shivaji, *Updated Constraints on CP-Odd Gauge-Higgs Operators,*(in preparation).

Conference/Workshops Attended:

1. *LHC and Dark Matter Workshop*, India, Feb, 2015,

2. *SERC School on High Energy Physics*, India, Dec, 2014 -Jan, 2015 .

Samrat Kadge

Research Summary:

I am currently studying the novel electronic/spintronic properties that emerge in Manganite Heterostructures especially at their interfaces using model hamiltonian techniques under the guidance of Dr. Pinaki Majumdar. The problem at hand is the appearance of Ferromagnetism at the interface of two Anti-Ferromagnetic insulating manganites. We are investigating the effects of doping due to band mismatch for which the long range Coulomb interaction is being treated at the mean field level using self consistent method and the thermal properties are evaluated using the Classical Monte Carlo scheme.

Conference/Workshops Attended:

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

Other Activities:

1. Tutoring the course on 'Condensed Matter Physics 2', instructed by Dr. Prasenjit Sen and Dr.Sumathi Rao (Jan-May, 2015).

Sudipto Singha Roy

Research Summary:

Diverse no-go theorems exist, ranging from no-cloning to monogamies of quantum correlations and Bell inequality violations, which restrict the processing of information in the quantum world. In a multipartite scenario, monogamy of Bell inequality violation and the exclusion principle of dense coding are such theorems which impede the ability of the system to have quantum advantage between all its parts. In ordered spin systems, the twin restrictions of translation invariance and monogamy of quantum correlations, in general, enforce the bipartite states to be neither Bell inequality violating nor dense codeable. We show that it is possible to conquer these constraints imposed by quantum mechanics in ordered systems by introducing quenched impurities in the system while still retaining translation invariance at the physically relevant level of disorder-averaged observables.

The length of classical correlators typically decays exponentially and polynomially for the gapped and the gapless ordered quantum spin systems respectively, at zero-temperature. In such systems, quantum entanglement decays exponentially even at the quantum critical point. However, Quantum discord, an information-theoretic quantum correlation measure, behaves like classical correlator. We have investigated the effects of quenched disorder on quantum correlation lengths, viz., entanglement and quantum discord, in the anisotropic XY and XYZ spin chains. We found that there is neither reduction nor enhancement in entanglement length while quantum discord length increases significantly in such systems.

Currently in another project we are studying characterization of multipartite entanglement properties for spin ladder system using an analytical technique which incorporates resonating valance bond type states and also using some numerical tools.

Publications:

1. 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)**

Preprints:

1. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, R. Prabhu, Aditi Sen(De), Ujjwal Sen *Enhancement of Quantum Correlation Length in Quenched Disordered Spin Chains,* arXiv:1503.04770

2. Sudipto Singa Roy, Himadri Sekhar Dhar, Debraj Rakhsit, Aditi Sen(De), Ujjwal Sen *Diverging scaling with converging multisite entanglement in Heisenberg ladders,* (in preparation).

Conference/Workshops Attended:

1. *One day QIC workshop* , HRI, November 2014.
   Presented a poster titled as *Beating no-go theorems by engineering defects in quantum spin models'*

2. *School on Topological Quantum Matter*, HRI, February, 2015.
   Presented a poster titled as *Enhancement of Quantum Correlation Length in Quenched Disordered Spin Chains,'*

3. *Young Quantum-2015 (YouQu-15)*, HRI, India, February 2015.
   Delivered a talk on *Beating no-go theorems by engineering defects in quantum spin models".*

Other Activities:

1. Member of local organizing committee of *Young Quantum (YouQu-15)*, Harish-Chandra Research Institute, February 2015.

Amit Kumar Pal

Research Summary

In the year 2014-2015, I pursued my research in various interesting directions of quantum information processing and applications. More specifically, we have looked into the dynamics of information-theoretic quantum correlations belonging to a genre different than the entanglement-separability paradigm, when the quantum system is subjected to noisy environments. One of the difficulties encountered in realizations of quantum information protocols is that the quantum correlations decohere rapidly by interaction with the environment. We have determined necessary and sufficient conditions for quantum correlations, as measured by the quantum discord and the quantum work deficit, to freeze, i.e., remain constant over time when bipartite as well as multipartite states are subjected to local noisy channels. We have pointed out that inhomogeneity in the magnetizations of the quantum states plays a crucial role in the freezing phenomena, and that there is a trade-off between the frozen value of the correlation and the duration of freezing.

Also, from an application-oriented point of view, we have considered quantum states for which quantum correlations, instead of an exact freezing, show an effective freezing property in the form of a very slow decay over time. We have introduced a freezing index to quantify the goodness of the exact as well as effective freezing behaviour, and showed that the freezing index can be used to detect quantum phase transitions.

In quantum communication, invention of entanglement distillation protocols to purify highly entangled states out of collection of states with relatively low entanglement has been proven crucial in order to overcome difficulties in the form of decoherence due to noisy quantum channels. We have introduced the notion of distillation under limited resources. The corresponding protocol, which we call the "canonical distillation of entanglement", leads to the set of canonically distillable states. We have pointed out that for non-interacting Hamiltonians, almost no states are canonically distillable, while the situation changes drastically for interacting ones. We have considered several paradigmatic interacting Hamiltonians for bipartite as well as multipartite quantum systems and probed the canonical distillability of quantum states in each case.

Preprints:

1. Titas Chanda, Amit Kumar Pal, Anindya Biswas, Aditi Sen De, and Ujjwal Sen, *To freeze or not to: Quantum correlations under local decoherence,* arXiv:1409.2096 [quant-ph]

2. Tamoghna Das, Asutosh Kumar, Amit Kumar Pal, Namrata Shukla, Aditi Sen De, and Ujjwal Sen, *Canonical Distillation of Entanglement,* arXiv:1411.7936 [quant-ph]

Conference/Workshops Attended:

1. *Young Quantum - 2015*, India, February, 2015.

Visits to other Institutes:

1. Bose Institute, Kolkata, India, August, 2014.

2. Bose Institute, Kolkata, India, September, 2014.

3. Bose Institute, Kolkata, India, March, 2015.

Other Activities:

1. Co-organizer of the inaugural meeting "Young Quantum - 2015" held at Harish-Chandra Research Institute, Allahabad, during February 24-26, 2015.

Juhi Dutta

Research Summary:

The existing Standard Model of Particle Physics fails to give a complete description of nature.Among the various proposed Beyond Standard Model theories,Supersymmetry is strongly motivated and has been extensively searched for at the LHC.However conventional SUSY search signals have so far not been observed.In this regard, we are focussing on studies of compressed supersymmetric spectrums and are looking for their possible signatures for detection in collider searches.

Md Arif Shaikh

Research Summary:

I joined the astrophysics group as a Ph.D. student in early 2015. I have been working on accretion processes in astrophysics. I first went through some standard literature on astrophysical fluid dynamics and reproduced the fluid dynamics equations from microscopic and macroscopic physics. I have now been studying the accretion process in the binary systems which involves Roche lobe overflow, Roche geometry and the evolution of the mass-transferring binaries – leading to the formation of standard accretion disc formation and produces the viscous torque in such discs. Finally I studied the standard disc model (the Shakura Sunyaev α disk). I studied Radial disc structure, steady thins discs, local structure of thin discs, the corresponding emitted spectrum. We have future plan to perform the stability analysis of the steady fully viscous Shakura Sunyaev α disk model.

Dibya Kanti Mukherjee

Research Summary:

I am currently investigating the presence of Andreev bound states in Weyl semimetal-superconductor (s-wave) heterostructures under the guidance of Prof. Sumathi Rao. The system is a semimetal-superconductor-semimetal-superconductor-semimetal structure and our goal is to study bound states composed of electrons and holes (which in turn is created by retro and specular Andreev reflections at a Weyl semimetal-superconductor junction) in the semimetal located between the two superconductors. At the values of energy for which such a bound state is obtained, we expect to see resonant peaks in conductance. This is also reciprocated by the presence of poles in the transmission amplitude at these energy values. Also, our present focus is on understanding Josephson effect in such systems by varying the relative superconducting phase.

Conference/Workshops Attended:

1. *Bangalore School on Statistical Physics - V , India, April, 2014.*
2. *School on Topological Quantum Matter, India, February, 2015.*

Arijit Dutta

Research Summary:

I have been studying the effect of strong bias on the transport properties of finite size strongly correlated quantum systems under the guidance of Prof. Pinaki Majumdar. We are currently developing a scheme which would capture perturbation effects beyond linear response, and also retain spatial fluctuations exactly. For implementing this scheme, we consider an interacting bulk (described by the Hubbard model) connected to non-interacting leads which are maintained at different potentials. The leads can be integrated out and the resulting action can be sampled using auxilliary field Monte Carlo to generate an ensemble of real space configurations, which can then be used to calculate non-linear response functions of the bulk. The method has been developed keeping in mind field driven breakdown problems for the future.

Conference/Workshops Attended:

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

Titas Chanda

Research Summary:

During the last academic year, I have been working on open quantum systems in various scenarios, mainly the study of quantum freezing phenomena and dynamics of multiparty quantum correlations in light-harvesting complexes.

In general every quantum correlation measures tend to decay under environmental noise, but there are cases in which it remain constant in time for a certain interval of time. Such interesting phenomena are known as quantum freezing. Although a few studies have addressed the issue of preserving quantum correlation measures during their dynamics, identifying the inherent property in quantum states, prohibiting the loss of quantum correlations over time, is still an open question. In our work, we have derived necessary and sufficient conditions for freezing of quantum correlations as measured by quantum discord (QD) and quantum work deficit (QWD), when a two-qubit state *with magnetization* is subjected to local depolarizing channels, in which bit-flip (BF), phase-flip (PF), or bit-phase-flip (BPF) errors can occur. We have shown that inhomogeneity in magnetization plays a crucial role for the freezing behavior of the state. The necessary and sufficient criteria show that there exist regions in which QD freezes while QWD does not, highlighting the necessity of proper choice of the quantum correlation measure to demonstrate the freezing phenomenon, and also that if the efficient performance of a certain quantum information task requires the freezing of a particular quantum correlation measure, the same may not remain efficient in a situation or environment where another quantum correlation is frozen. For both QD and QWD, we propose a complementarity relation between the value of quantum correlation measure during the freezing interval and the duration of the interval. For the class of states for which freezing is observed, we find a correspondence between the quantum entanglement of the initial state and its freezing properties. The study is extended to multipartite states where two prescriptions for generating multipartite freezing states are proposed. Like decoherence-free subspaces, introduced to protect qubits, the generated inherently decoherence-free states can be a building block of quantum memory in which quantum correlation in the form of QD or QWD can be stored. Also there exists a large class of states for which quantum correlations do not freeze, but the change in quantum correlations is very slow with time. Hence it is interesting to quantify the freezing quality of a quantum correlation measure. We introduce a measure to quantify the goodness of freezing and call the measure as the "freezing index". We then apply the measure to characterize the "effective freezing"of QD present in the anisotropic quantum XY model in a transverse field, which appears in the description of certain solid-state realizations, as well as in that of controlled laboratory settings. Moreover, we have shown that the index is capable of detecting the quantum phase transition in the model.

In the last few years, quantum coherence and quantum correlations have been claimed to be of relevance in certain biological processes. Two important biological phenomena in which quantumness may play a role include avian magnetoreception, used by migratory birds for efficient navigation, and the Fenna-Mathews-Olson (FMO) light-harvesting protein complex of green sulfur bacteria, responsible for photosynthesis. In the latter process, the FMO complex plays the role of the mediator to transfer excitation energy from the light-harvesting chlorosome antennae to a reaction center. Recently, it was argued that the efficient transfer of energy in photosynthesis can not be explained by the classical incoherent hopping model. On the other hand, several studies show that quantum coherence is essential in excitation energy transfer in the FMO complex. Specifically, the dynamics of entanglement under the influence of dissipative environments, both Markovian and non-Markovian, have been extensively investigated. In this work, we have investigated the dynamics of monogamy-based multipartite quantum correlation measures, specifically, negativity and discord monogamy scores, as well as collections of quantum correlations in the different bipartitions. The investigations are carried out for the fully connected network as well as for the FMO complex. To understand the effects of decoherence in the energy transfer, the evolution of multiparty quantum correlations are studied through the Lindblad mechanism, including dissipation and dephasing effects, with the initial states being close to the antenna. We have found that the behavior of multipartite quantum correlation measures depend both on the initial state as well as the "nodal" observer used in the monogamy scores. The results show that in the FMO complex, the negativity monogamy score is more robust against noise than its bipartite counterpart, irrespective of the choice of the nodal observer and the initial state. We have observed a complementary behavior between the dynamics of negativity and discord monogamy scores in the presence of noisy environments, both in the fully connected network model and in the FMO complex. In particular, we have found that in the FMO complex, the modulus of the discord monogamy score possesses much smaller values as compared to the quantum discord present in the constituent bipartite states – the situation is opposite in the case of negativity. The findings clearly indicate that to detect quantum correlations in the FMO complex, multipartite entanglement measures are more effective than the bipartite ones. The opposite is true for quantum discord. Moreover the dynamics of quantum correlations allows us to classify the seven inequivalent sites of the FMO complex into three groups, which in turn helps us to predict the structural arrangement of the complex. Interestingly, if we look at collections of the quantum correlations in different bipartitions, and investigate their behavior as they evolve in time, then their relative values indicate the route through which the energy is transformed from the antenna to the bacterial reaction center.

Publications:

1. Titas Chanda, Amit Kumar Pal, Anindya Biswas, Aditi Sen De, Ujjwal Sen, *Freezing of quantum correlations under local decoherence*, Phys. Rev. A (in production, arXiv:1409.2096).

Preprints:

1. Titas Chanda, Utkarsh Mishra, Aditi Sen De, Ujjwal Sen, *Time dynamics of multiparty quantum correlations indicate energy transfer route in light-harvesting complexes*, arXiv:1412.6519.

Conference/Workshops Attended:

1. *Young Quantum-2015*, Harish-Chandra Research Institute, Allahabad, India, February, 2015.

Invited Lectures/Seminars:

1. *Time dynamics of multiparty quantum correlations indicate energy transfer route in light harvesting complexes*, Young Quantum-2015, Harish-Chandra Research Institute, Allahabad, India, February, 2015.

Other Activities:

1. Tutor for the course "Atomic and Molecular Physics", August-December, 2014.

Ruchi Saxena

Research Summary:

I am working on a topological material Silicene which is identical to graphene but unlike graphene it has many striking aspects. It is an excelllent candidate to realise Kane-Mele model. It has Spin-orbit coupling thousands times greater than graphene which actually provides mass to dirac electorns. Since it is a topological material so people are always interested to look all the properties which are already known in graphene. It has similar honey comb structure like graphene but opposed to graphene it has buckled structure i.e. two sublattices in silicene are not coplanar but are separated by some perpendicular distance. Hence when it is placed in external electirc feild then two sublattices have potential difference. It provides a parameter which can be externally controlled by changing electric feild. By tunning of this parameter E_z we can close the gap to have semimetal phase and again re-open it to have insulator phase. Hence it actually bridges a gap among three phases of matter which are topological, semimetal and insulator.

I am studying junctions made up of silicene namely Ferromagnetic-Normal-Ferromagnetic silicene and Ferromagnetic-Superconducting silicene. Silicene itself is not a ferromagnetic or superconducting. We induce these properties in silicene by proximity effect like we can do the same in graphene. While studying these junction we are interested in transport properties of such systems. We are mainly looking at Charge conductance, Valley conductance, TMR(Tunneling Magneto Resistance) and Spin polarization. All these properties are extremely essential to realize valleytronis and spintronics.

Conference/Workshops Attended:

1. *School on topological quantum matter*, India, February 2015
2. *International Symposium on Clusters, Cluster Assemblies and Nano-scale Materials (ISCANM-III)*, India, March 2014.
3. *School and Workshop on Physics of Cold Atoms*, India, Februar 2014.
4. *Meeting on Quantum Information Processing and Applications (QIPA-2013)* , India, December 2013.
5. *Meeting on Transport in Topological Insulators* , India, July 2013.

Mritunjay Kumar Verma

Research Summary:

In the acedemic year 2014-15, I have been involved in a project which is in collaboration with Arnab Rudra, Sourav Sarkar and Rajesh Gopakumar. In this project, we are trying to analyze the Conformal field theories (CFT) in Mellin space with the goal to implement open closed string duality in large N limit. This requires the Feynman like rules for the CFTs in Mellin space. We have obtained the Feynman rules at tree level and at present working out the loop level rules. The successful implementation of open closed string duality will be a significant step towards proving the AdS/CFT duality.

Preprints:

1. Rajesh Gopakumar, Arnab Rudra, Sourav Sarkar, Mritunjay Verma *Feynman Rules and Schwinger Times in Mellin Space-1,*

Conference/Workshops Attended:

1. *Black Hole Information paradox*, Harish Chandra Research Institute-, India, Fabruary, 2014

2. *Advanced String School*, Puri, India, September, 2014

3. *Indian Strings Meet*, Puri, India, December, 2014

4. *Spring School on Superstring and Related Topics*, ICTP, Italy, March, 2015

Sitender Pratap Kashyap

Research Summary:

I did the following things in order

1. Studied string theory and followed the following reference
   - String Theory by Joseph Polchinski volume 1 (chapter 1-7 and parts of chapter 8 and 9) and volume 2 (till section 10.4)
   - Joe's Little book of String
2. Started a project on Pohlmeyer reduction and read some papers. Abandoned the project after sometime.
3. Currently working on computing scattering amplitudes in field theory (specifically N=4 superyang mills) using the pure spinor formalism.

Conference/Workshops Attended:

1. *Advanced String School*, India, September, 2014.
2. *Indian Strings Meeting-14*, India, December, 2014.

Harshant Singh

Research Summary:

I have been working with coarse grained chemical models of growing cells, simulating such models using Gillespie's stochastic simulation and Tau Leaping algorithms. My main objective is to use these coarse grained models and reproduce chemical number distributions of growing cells available from various experimental studies. I study the interplay between the features of the dynamics of such models and the characteristics of the number distributions one obtains by simulating them.

Abhishake Sadhukhan

Research Summary:

It is known that the string worldsheet theory in $AdS \times M$ backgrounds are integrable. Here M is a compact manifold. Hence it is natural to ask if the similar integrable structure exists for deformed AdS backgrounds. We have shown that the background $AdS_3 \times S^3 \times S^3 \times S^1$ supported by mixed Ramond Ramond and Neveu Schwarz fluxes. We consider the Type IIB supergravity equations for this background and construct the most general case of mixing parameters between the Ramond Ramond field and Neveu Schwarz field. The background is

$$ds^2 = ds^2_{AdS} + ds_1^2 + ds_2^2 \tag{1}$$

where ds^2_{AdS} represents the following AdS_3 global metric

$$ds^2_{AdS} = R_3^2(-\cosh^2\rho\, dt^2 + d\rho^2 + \sinh^2\rho\, d\phi^2) \tag{2}$$

while ds_1^2 and ds_2^2 are the line elements of the two 3 spheres.

$$\begin{aligned} ds_1^2 &= R_1^2\left(d\beta_1^2 + \cos^2\beta_1(d\beta_2^2 + \cos^2\beta_2 d\beta_3^2)\right), && (3)\\ ds_2^2 &= R_2^2\left(d\beta_4^2 + \cos^2\beta_4(d\beta_5^2 + \cos^2\beta_5 d\beta_6^2)\right) && (4)\end{aligned}$$

We choose the following ansatz for RR and NSNS flux to solve these equations

$$\begin{aligned} F_{123} &= 2b_1R_1^2\cos^2\beta_1\cos\beta_2, \qquad H_{123} = 2b_4R_1^2\cos^2\beta_1\cos\beta_2, && (5)\\ F_{456} &= 2b_2R_2^2\cos^2\beta_4\cos\beta_5, \qquad H_{456} = 2b_5R_2^2\cos^2\beta_4\cos\beta_5, && (6)\\ F_{t\rho\phi} &= 2b_3R_3^2\cosh\rho\sinh\rho, \qquad H_{t\rho\phi} = 2b_6R_3^2\cosh\rho\sinh\rho, && (7)\end{aligned}$$

Here the indices $1, 2, 3...$ on F and H refer to $\beta_1, \beta_2, \beta_3...$ After solving the supergravity equations one can check that

$$b_1 = b_2 = b_3, \quad b_4 = b_5 = b_6 \tag{8}$$

The radii are also related by the following relation and it can be seen that there are two unfixed parameters in the theory α and β.

$$\frac{R_3^2}{R_1^2} + \frac{R_3^2}{R_2^2} = 1, \quad \cos^2\alpha + \sin^2\alpha = 1 \tag{9}$$

$$b_i^2 + b_{(i+3)}^2 = 1, \quad \cos^2\beta + \sin^2\beta = 1 \tag{10}$$

where $i = 1, 2, 3$. The Lax pair of this background can then be constructed by writing out the Nambu Goto action and this can be shown to be integrable.

Conference/Workshops Attended:

1. *Indian Strings Meeting*, India, December 2014.

Visits to other Institutes:

1. Indian Institute of Science, Bangalore, February, 2015

Trilochan Bagarti

Research Summary:

In the last one year I have worked on the following problems:
I have studied the problem of population extinction in an inhomogeneous host-pathogen model. I have used reaction-diffusion equations with quenched disorder to model the system. The quenched disorder serves as habitats for the host species. The host are confined in there habitats and the pathogen disperses via diffusion. The model qualitatively explain global extinction of amphibians in lake basin system observed experimentally. In this model we show that the pathogen spreads in a wave like pattern infecting the entire lake basin system. By linear stability analysis we show that the host population at an infected lake decays exponentially at rate proportional to the square of the steady state population. The time of extinction and the speed of the travelling wave are computed.
I have studied synchronization of Kuramoto oscillators in an evolving network. In this model the topology of the network evolves stochastically which is decided locally by the phase of the oscillators. As time progresses new edges between nodes are formed and older ones broken solely by the dynamics of the individual oscillators. Starting from a collection of uncoupled oscillators we investigate how synchronization emerges as the network evolves. As the system converges reaches synchronization we have found a steady state network topology. The properties of the steady state networks are studied. This work is done in collaboration with Mr. R. K. Singh, IMSc, Chennai.

Preprints:

1. Trilochan Bagarti, *Population extinction in an inhomogeneous host-pathogen model*,arxiv:1501.01603

2. R. K. Singh and Trilochan Bagarti, *Synchronization in an evolving network*(in preparation)

Visits to other Institutes:

1. Institute of Physics, Bhubaneswar, India, January 2015.

2. Institute of Mathematical Sciences, Chennai, India, March 2015.

Invited Lectures/Seminars:

1. *Inhomogeneous reaction diffusion models*,
   Talk, IOP, Bhubaneswar, January 13, 2015.

2. *Inhomogeneous reaction diffusion models*,
   Talk,IMSc, Chennai, March 27, 2015.

Soumini Chaudhury

Research Summary:

During April to August 2014, as a part of my PhD thesis, I have been studying the phase space characteristics of the dark matter (DM) component of our Galaxy, the Milky Way, and their implications for the analysis of the results of the direct detection experiments that are searching for the Weakly Interacting Massive Particle (WIMP) candidates of DM. In order to analyze and interpret the results from DM direct detection (DD) search experiments, one needs two crucial astrophysical inputs, namely, the local (i.e., the Solar neighborhood) density of DM ($\rho_{DM\odot}$) and the local velocity distribution function (VDF) of the DM particles constituting the Galactic halo, which are currently not known with certainty. Towards this end, we attempted to determine the parameters of the phase-space distribution function (PSDF) from rotation curve (RC) data, pertaining to the Milky Way.

We have presented a comprehensive study of the derivation of the $\rho_{DM\odot}$, using RC data of our Galaxy extending up to $\sim$ 200 kpc for various Galactic Constants (GCs) sets, by adopting four different profiles for the Galactic DM halo model. The parameters of the models have been determined by fit to the RC data by a Markov Chain Monte Carlo analysis. We have found that the best fit $\rho_{DM\odot}$ is fairly independent of the DM halo density profile (be it cored or cuspy) and rather shows a monotonic behavior with the value of $V_\odot$ value of the GCs set chosen. Specifically it varies by a factor of $\sim$ 3 (from ~ 0.2 to $\sim 0.6\ \mathrm{GeV/cc}$ for $V_\odot$ changing from 200 to 244 km/sec) within the chosen $V_\odot$ range. The global properties like halo virial radius, total virial mass etc. which are dependent on the large distance behavior of RC data, are seen to be uncorrelated to the $V_\odot$ values since it has been observed that RC profile beyond the disk region is insensitive to the GCs set adopted.

Next, we have derived the PSDF of the WIMPs by "inverting" the best fit Einasto density profile using Osipkov-Merritt formalism including the effect of the gravitational influence of visible matter (VM) on DM in a self consistent manner. The PSDF so obtained is characterized by an anisotropic velocity space and parametrized by an anisotropy radius, r_a, within which the VDF has a nearly isotropic behavior with a lower bound found at 4 kpc (with local $\beta(r) \leq$ 0.81). The effect of gravitational influence of VM is significant up to $\sim$ Solar radius and found to support higher radial and tangential values and introduce an additional broad peak in the inner Solar circle region for the velocity dispersions. However, the VM effect decreases with higher radii, as expected. Our findings have significant implications for the analysis and interpretation of the results of DD experiments, which we propose to study in more detail in future.

Since September 2014, as a post doctoral fellow in the Astrophysics group at HRI, Allahabad, I have started working on black hole accretion physics. Analytical treatment of black hole accretion generally presumes the stability of the stationary configuration. Various authors in the past several decades demonstrated the validity of such an assumption for inviscid hydrodynamic flow. Introduction of a weak viscosity, as a first order linear correction involving the viscosity parameter (α), however, may sometimes provide a more detail understanding of the observed spectrum. We study the stationary solutions for the aforementioned quasi-viscous flow for all possible geometric configuration of the matter flow. For a sufficiently low range of the viscosity parameter both one and three critical point solutions have been found for allowed ranges in the astrophysical parameters under the post-Newtonian scheme in an dynamical analysis treatment. With the introduction of the viscosity parameter, the only feasible critical points of this 'quasi-viscous' flow are saddle and spirals in contrary to the inviscid case where spirals are replaced by centre type critical points. We perform the linear stability analysis of the time dependent quasi viscous accretion as well.

In a stationary, general relativistic, axisymmetric, inviscid and rotational accretion flow, described within the Kerr geometric framework, transonicity has also been examined by setting up the governing equations of the flow as a first-order autonomous dynamical system. The consequent linearized analysis of the critical points of the flow leads to a comprehensive mathematical prescription for classifying these points, showing that the only possibilities are saddle points and centre-type points for all ranges of values of the fixed flow parameters for all possible geometric configuration of the matter flow. The flow topology under shock generation has been studied in detail with emphasis on near horizon behavior of relevant physical quantities. The spin parameter of the black hole (a) influences the multi transonic character of the flow, as well as some of its specific critical properties. The investigation of the behavior of accretion disks with isothermal fluid under quasi viscous condition and the flow topology is under progress.

Preprints:

1. Pijushpani Bhattacharjee, Soumini Chaudhury and Susmita Kundu, *Local Dark Matter Density in the Light of Rotation Curve Data of Our Galaxy,* (in preparation)

2. Soumini Chaudhury, Susmita Kundu and Pijushpani Bhattacharjee, *Probing Galactic Dark Matter Velocity Anisotropy using Rotation Curve Data,* (in preparation)

3. D. B. Ananda, S. Chaudhury, T. K. Das, I. Maity and S. Nag, *Quasi-viscous accretion for various geometric configurations,* (in preparation)

4. D. B. Ananda, S. Chaudhury, T. K. Das and P. Tarafdar, *Critical and quasi-terminal behaviour of axisymmetric flow with energy preserving discontinuities in the Kerr metric,* (in preparation)

5. D. B. Ananda, S. Chaudhury, T. K. Das and P. Tarafdar, *Critical and quasi-terminal behaviour of axisymmetric flow with temperature preserving dissipative discontinuities in the Kerr metric,* (in preparation)

Conference/Workshops Attended:

1. *Winter School on The Central Region of Spiral Galaxies*, IUCAA, Pune, India, January 2015

2. *Workshop on Off-the-Beaten-Track Dark Matter and Astrophysical Probes of Fundamental Physics*, The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, April 2015

Visits to other Institutes:

1. Saha Institute Of Nuclear Physics, Kolkata, India, January - February, 2015.

Invited Lectures/Seminars:

1. *Rotation Curve of the Milky Way and the Phase-Space Structure of its Dark Matter Halo: Implications for Direct Detection of Weakly Interacting Massive Particle candidates of Dark Matter*, Thesis defence seminar in Physical Sciences, Saha Institute Of Nuclear Physics, Kolkata, February 2015.

Academic recognition/Awards:

- Awarded Ph.D. degree by Homi Bhabha National Institute, Mumbai, April 2015.

Other Activities:

1. Supervision of Shefali Jaiswal, Masters first year from Indian School of Mines, Dhanbad on a project regarding construction of rotation curve data of Milky Way from suitable tracer data sets, December, 2014

2. Mentoring project works of Ph.D. students (Avirup Ghosh, Khorshed Alam) as a part of their course work in HRI, November 2014 - April 2015.

Priyanka Mohan

Research Summary:

The research problem I have been working on with Prof. Sumathi Rao in the last academic year is that of a 1D Kitaev like spin model. This model, known as the tetrahedral chain, consists of plaquettes strung together to form a 1D chain. The phase diagram and the possible edge Majorana modes in this chain were calculated exactly using a Majorana fermion representation. We studied this model using the slave fermion formalism. This is done by representing the spin operators by slave fermions followed by a Hubbard-Stratonovich decoupling in the hopping and the superconducting channels. The resulting Hamiltonian was diagonalized exactly to give the energy bands in the model. The phase diagram of this model consists of both gapped and gapless phases. We are currently calculating the effects of three spin interactions and the spin-spin correlations in both the gapped and gapless phases.

Preprints:

1. Priyanka Mohan and Sumathi Rao, *Slave fermion formalism for the tetrahedral chain,* in preparation

Conference/Workshops Attended:

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

Namrata Shukla

Research Summary:

A project on canonical distillation of entanglement was completed. Entanglement being a resource for any kind of quantum information protocol and considering its interaction with environment resulting into the decoherence, it is very important to distill the maximally entangled states from many copies of arbitrarily entangled states. Within the given resource in the form of energy, we have developed a scheme for distillation of entanglement and we call it canonical distillation. We have tried to present a definite picture of state space in view of distillable and canonically distillable states.

The other project that I explored is about proving new error-disturbance relations in the process of a quantum measurement of two incompatible observables. We have found very interesting error-disturbance uncertainty relations which provide better bound than the best available uncertainty relations concerning error and disturbance during the quantum measurement. In future, this formalism may be more efficient in detection of entanglement as it is more important to know the error-disturbance inequalities in order to experimentally perform the realistic quantum measurement.

I have also been doing another project on phase deficit and entanglement. This is about detection of entanglement in bipartite quantum system by observing the change in phase during a quantum evolution in both global and local pictures. This work is almost nearing completion and to be arxived soon.

Preprints:

1. T. Das, A. K. Pal, N. Shukla, A. K. Pal and U. Sen, *Canonical Distillation of Entanglement* arXiv:1411.7936.

2. C. Mukhopadhyaya, N. Shukla and A. K. Pati *Stronger Error Disturbance Relations for Incompatible Quantum Measurements* arXiv:1503.05085.

3. N. Shukla and A. K. Pati *Entanglement and Phase Deficit* in preparation.

Conference/Workshops Attended:

1. *4 th International Conference on Quantum Cryptography*, France, September 2014.

2. *Young Quantum Meeting*, India, February 2015

Visits to other Institutes:

1. IISER, Pune, November 2014

Other Activities:

1. An Interview with Prof. Ashoke Sen for All India Radio , December 2014.

2. Organizing committee member for Young Quantum-2015 at HRI, February 2015.

Arindam Chatterjee

Research Summary:

During the last academic year, my work has been focused on Dark Matter (DM) and phenomenology of Supersymmetry (SUSY).
In the minimal supersymmetric standard model (MSSM), the lightest neutralino is the only DM candidate. Therefore most SUSY searches assume it to be at the bottom of the MSSM spectrum. It has been shown that left-sneutrinos can also be DM candidate if there is a tiny [O(100 KeV)] mass difference present between its CP-even and CP-odd components. We have shown that such a DM can have right thermal relic density over a wide range of the parameter space. In particular, co-annihilation effects with bino–like neutralino and squarks can help in achieving the right thermal relic density staring from 300 GeV to heavier masses of order TeV (Publication no. [3]). Further, we have shown that the corresponding SUSY spectrum can have very clean same-sign tri-lepton signal at Large Hadron Collider (LHC), the flavor of at least two of the leptons bearing the signature of the flavor of the sneutrino (Preprint no. [2]).
In the context of next-to-MSSM (NMSSM), we have shown that the presence of light 3rd generation squarks can lead to interesting tri-lepton and/or four-lepton signals which can be probed at the LHC (Preprint no. [1]).

Publications:

1. A. Chatterjee, A. Choudhury, A. Datta, B. Mukhopadhyaya; *Gluino mass limits with sbottom NLSP in coannihilation scenarios*, Journal of High Energy Physics, **2015**, Issue 1, (2015).

2. A. Chatterjee, A. Mazumdar; *Bound on largest $r \lesssim 0.1$ from sub-Planckian excursions of inflaton*, Journal of Cosmology and Astroparticle Physics, **2015**, Issue 1, (2015).

3. A. Chatterjee, N. Sahu; *Resurrecting L-type sneutrino dark matter in light of neutrino masses and LUX data*, Physical Review D, **90**, Issue 9, 095021, (2014).

Preprints

1. J. Beuria, A. Chatterjee, A. Datta, S. K. Rai; *Two light stops and the LHC*, arXiv:1505.00604.

2. N. Chakrabarty, A. Chatterjee, B. Mukhopadhyaya; 'it Same-sign trileptons with a left-sneutrino as the lightest minimal supersymmetric particle", arXiv:1411.7226.

Conference/Workshops Attended:

1. *LHCDM*, IACS, India, Feb., 2015,

2. *Statcosmo*, ISI, India, Feb., 2015.

3. *Saha Theory Workshop*, SINP, India, Feb., 2015.

4. *PASCOS*, ICTP, Italy, June, 2015.

Ambresh Shivaji

Research Summary:

During April 1, 2014 to March 31, 2015 I have carried out following three works.

- We studied the production of electroweak vector boson in association with the standard model Higgs and a light jet via gluon fusion at the LHC. We have computed $gg \to VHg$, ($V = \gamma, Z$) at the leading order which take place at one-loop via quark loop. Due to a large gluon flux at the LHC, such loop-induced processes can have sizable cross sections. Loop-induced processes are expected to be sensitive to new physics effects, therefore it is important that the SM predictions for such processes are available. In our study we have predicted the hardonic cross section for VHj processes and discussed certain kinematic distributions of importance at the LHC.

- The 7+8 TeV LHC data has ruled out a large parameter space for many models of new physics. We have taken a model independent approach to study new physics that may arise from the Higgs sector. In this regard, we have considered CP-odd gauge invariant dimension six operators and with the help of various experimental data available we have constrained their parameters. The the outcome of our analysis can be used to study the effect of CP violating VVH couplings at the LHC.

- We have also computed the next-to-leading order (NLO) QCD corrections to the *vector diquark* production at the LHC. Diquarks are exotic colored particles which naturally arise in many extensions of the standard model like grand unified theories. The NLO QCD corrections significantly reduce the renormalization scale dependence of the cross section.

Publications:

1. Pankaj Agrawal, Ambresh Shivaji *Gluon Fusion Contribution to VHj Production at Hadron Colliders*, Phys. Lett. B **741**, 111, (2015)

2. Kenji Nishiwaki, Saurabh Niyogi, Ambresh Shivaji , *ttH anomalous coupling in double Higgs production*, JHEP **04**, 011, (2014)

Preprints:

1. Kasinath Das, Swapan Majhi, Santosh Kumar Rai, Ambresh Shivaji, *NLO QCD corrections to the resonant Vector Diquark production at the LHC* (in preparation),

2. Siddharth Dwivedi, Dilip Kumar Ghosh, Biswarup Mukhopadhyaya, Ambresh Shivaji, *Constraints on CP-Odd Gauge-Higgs Operators* (in preparation) .

Conference/Workshops Attended:

1. *Workshop on LHC and Dark Matter*, India, Feb 2015,

2. *Meeting of the Belgian Inter-University Attraction Pole network on fundamental interactions*, Belgium, December 2014.

Visits to other Institutes:

1. Saha Institue of Nuclear Physics, Kolkata, India, March 2015,

2. Vrije Universiteit Brussels, Brussels, Belgium, Nov. 2014,

3. Centre for Cosmology, Particle Physics and Phenomenology (CP3), Lovain-la-Neuve, Belgium, October 2014-January 2015.

Invited Lectures/Seminars:

1. *Loop-induced gluon fusion processes at the LHC*, Workshop on LHC and Dark Matter, HRI Allahabad and IACS Kolkata, IACS Kolkata, February 2015.

R. Prabhu

Research Summary:

During the academic year 2014-2015, I have carried out my research work on different aspects of quantum information and its interface with the many-body physics and quantum optics. In particular, I investigated the behavior of quantum correlation and its usefulness in different quantum information processing tasks in multiparticle systems by collaborating with students, post-docs and faculties of the Quantum Information and Computation group at HRI.

Following are the succinct description of the work done during this academic year:

- We showed that arbitrary multiparty quantum states can be made to satisfy monogamy by considering increasing functions of any bipartite quantum correlation that may itself lead to a non-monogamous feature.

- We established a relation between the capacity of multipartite dense coding and multipartite quantum correlation measures of arbitrary multiqubit states. This correspondence is illustrated both in the case of noiseless and noisy channels for arbitrary shared quantum states.

- Used a genuine multipartite entanglement measure to study quantum phase transitions in 1d- and 2d-spin models which are not integrable.

- We proved that almost all pure quantum states of systems consisting of a large number of subsystems are monogamous with respect to all quantum correlation measures of both the entanglement-separability and the information-theoretic paradigms, indicating that the volume of the monogamous pure quantum states increases with an increasing number of parties.

- We probed the one-dimensional arrays of quantum spin-1/2 particles, governed by the Heisenberg spin glass Hamiltonian with natural or engineered quenched disordered couplings in an external magnetic field. We found that these systems allow the order from disorder phenomenon – disorder-induced enhancement – for magnetization, classical correlators, and bipartite as well as multipartite entanglement, wherein a disordered system has a higher value of the quenched averaged physical observable than in the corresponding ordered system.

- We 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.

- In case of paradigmatic quenched disordered quantum spin models, viz., the XY spin glass and random-field XY models, we showed that quenched averaged quantum correlations can exhibit the order-from-disorder phenomenon for finite-size systems as well as in the thermodynamic limit. Moreover, we find that the order-from-disorder can get more pronounced in the presence of temperature by suitable tuning of the system parameters.

- We investigated the quantum correlation lengths for ground states of certain spin chains and showed that the entanglement lengths cannot be improved significantly in these quenched disordered systems, however the lengths of information-theoretic quantum correlation measures can substantially be enhanced in such systems.

Publications:

1. Salini K., R. Prabhu, Aditi Sen (De), and Ujjwal Sen, *Monotonically increasing functions of any quantum correlation can make all multiparty states monogamous,* Ann. Phys. **348**, 297 (2014).

2. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Multipartite Dense Coding vs. Quantum Correlation: Noise Inverts Relative Capability of Information Transfer,* Phys. Rev. A **90**, 022319 (2014).

3. Anindya Biswas, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Genuine Multipartite Entanglement Trends in Gapless-gapped Transitions of Quantum Spin Systems,* Phys. Rev. A **90**, 032301 (2014).

4. Asutosh Kumar, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Effect of a large number of parties on the monogamy of quantum correlations,* Phys. Rev. A **91**, 012341 (2015).

Preprints:

1. Utkarsh Mishra, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Constructive Interference Between Disordered Couplings Enhances Multiparty Entanglement in Quantum Heisenberg Spin Glass Models,* arXiv:1408.0179 [quant-ph].

2. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Distributed Quantum Dense Coding with Two Receivers in Noisy Environments,* arXiv:1412.6247 [quant-ph].

3. Debasis Sadhukhan, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Thermal Fluctuations Enhance Order-from-Disorder of Quantum Correlations in Quenched Disordered Spin Models,* arXiv:1412.8385 [quant-ph].

4. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Enhancement of Quantum Correlation Length in Quenched Disordered Spin Chains,* arXiv:1503.04770 [quant-ph].

Conference/Workshops Attended:

1. *"Networking-cum-Discussion" meeting for INSPIRE faculty awardees*, IISER Mohali, India, March, 2015.

2. *Young Quantum – 2015*, Harish-Chandra Research Institute, Allahabad, February, 2015.

Visits to other Institutes:

1. Indian Institute of Science Education and Research, Mohali (March, 2015).

2. Jamia Milia Islamia, New Delhi (February, 2015).

3. Indian Institute of Technology, New Delhi (January, 2015).

4. School of Physical Sciences, JNU, New Delhi (January, 2015).

5. Indian Institute of Science Education and Research, Kolkata (November, 2014).

6. National Institute of Science Education and Research, Bhubaneswar (November, 2014).

7. Raman Research Institute, Bengaluru, Karnataka (September, 2014).

8. Jawaharlal Nehru University, New Delhi (June, 2014).

Invited Lectures/Seminars:

1. *Quantum communication networks*, Indian Institute of Science Education and Research, Mohali, (March, 2015).

2. *Quantum communication networks*, Jamia Milia Islamia, New Delhi (February, 2015).

3. *Quantum communication networks*, Indian Institute of Technology, New Delhi (January, 2015).

4. *Quantum communication networks*, School of Physical Sciences, JNU, New Delhi (January, 2015).

5. *Multipartite quantum correlations in many-body systems*, Indian Institute of Science Education and Research, Kolkata (November, 2014).

6. *Multipartite quantum correlations*, National Institute of Science Education and Research, Bhubaneswar (November, 2014).

7. *Quantum communication networks*, Raman Research Institute, Bengaluru, Karnataka (September, 2014).

Other Activities:

1. Mentoring Mr. Biswajit Sahoo for his numerical project undertaken as numerical methods course work at Harish-Chandra Research Institute (HRI), Allahabad, August, 2014 - June 2015.

2. Mentor of Mr. Anirudha Bose (IIIT–Bhubaneshwar) under "Visiting Students Program" at HRI, Allahabad, September - October, 2014.

3. Mentor of Ms. Meeru Kumari (NISER, Bhubaneswar) under visitors program at HRI, Allahabad, July - August, 2014.

4. Mentor of Mr. Vibhuti Bhushan Jha (IIST, Thiruvananthapuram) under "Joint Science Academies Summer Research Fellowship Program for 2014" at HRI, Allahabad, May - July, 2014.

5. Mentor of Mr. Tomoghna Das for the course work project on "Quantum Information in Continuous Variable Systems" at HRI, January - May, 2014.

6. Co-organizer of the Young Quantum – 2015, Harish-Chandra Research Institute, Allahabad, February 24-26, 2015.

7. Referee of international journals like Annals of Physics, Journal of Applied Mathematics and Physics, Physical Review A, Physical Review E, Physical Review Letters, and Indian journals like Pramana and Proceedings of the National Academy of Sciences, India Section A: Physical Sciences.

8. Member of Cluster Committee at Harish-Chandra Research Institute, Allahabad.

Masazumi Honda

Research Summary:

In the academic year 2014-2015, I have been working on three dimensional supersymmetric gauge theory, which is related to string and M-theory.

First, I have computed partition functions of orbifold ABJM theory with Sanefumi Moriyama and ABJ theory with Kazumi Okuyama, which are expected to be dual to M-theories on certain orbifolds via AdS/CFT correspondence. We have determined structures of the partition functions including non-perturbative effects in string/M-theory.

Furthermore, I have developed a tool, which can obtain information on theories without supersymmetry at finite values of parameters. This tool is interpolating function between expansions of physical observables around different two points in parameter space. I have introduced a new type of smooth interpolating function and discussed that we can construct enormous number of interpolating functions in principle, which give the same two perturbative expansions up to some orders. I have pointed out that this fact leads us to "landscape problem of interpolating functions". Namely, while the "best" approximation of the physical quantity should be unique among the interpolating functions, when we do not know the exact result, it is unclear which interpolating function gives the best answer. Then we have proposed a criterion to determine the "best" interpolation in terms of the both expansions and explicitly checked the criterion in various examples including 2d Ising model, 4d $SU(3)$ pure Yang-Mills theory on lattice and $c = 1$ string theory.

Publications:

1. T. Azeyanagi, M. Hanada, M. Honda, Y. Matsuo and S. Shiba, *A new look at instantons and large-N limit,* JHEP **1405**, 008 (2014)

2. M. Fujitsuka, M. Honda and Y. Yoshida, *Higgs branch localization of 3d N=2 theories,* PTEP **2014, no. 12**, 123B02 (2014)

3. M. Honda and S. Moriyama, *Instanton Effects in Orbifold ABJM Theory,* JHEP **1408**, 091 (2014)

4. M. Honda and K. Okuyama, *Exact results on ABJ theory and the refined topological string,* JHEP **1408**, 148 (2014)

5. M. Honda, *On Perturbation theory improved by Strong coupling expansion*, JHEP **1412**, 019 (2014)

Conference/Workshops Attended:

1. *Indian Strings Meeting 2014*, India, December, 2014

Invited Lectures/Seminars:

1. *Instanton Effects in Orbifold ABJM Theory*, HRI String group Seminar, HRI, Allahabad, April, 2014.
2. *Exact results on ABJ theory and the refined topological string*, HRI String group Seminar, HRI, Allahabad, December, 2014.
3. *Instanton effects in string/M-theory from 3d superconformal field theories*, Indian Strings Meeting 2014, HRI, Puri, December, 2014.
4. *Supersymmetric index on $T^2 \times S^2$ and elliptic genus*, HRI String group Seminar, HRI, Allahabad, March, 2015.

Madhuparna Karmakar

Research Summary:

During this period of time the work carried out by me was principally concentrated on understanding the physics of spin imbalanced fermionic systems. The s-wave superconductivity is being studied in the two dimensional attractive Hubbard model in an applied magnetic field at the extreme Pauli limit where the orbital critical field is much greater than the Zeeman critical field and at a coupling corresponding roughly to the peak T_c in the BCS to BEC crossover window. The phase diagram of the system is being established by retaining the crucial amplitude and phase fluctuations. It has been observed that at low field, the superconductor undergoes a second order thermal transition to the normal state, and is only weakly magnetized near T_c. At intermediate fields the thermal transition is still second order, but the magnetization near T_c is significantly larger, characteristic of a 'breached pair' state. At strong field, the thermal transition is first order and our Monte Carlo reveals the presence of a metastable Fulde-Ferrell-Larkin- Ovchinnikov (FFLO) state. At even higher fields we observe the true FFLO ground state. The full thermal phase diagram of this strong coupling problem, reveals that the T_c scales are an order of magnitude below the mean field estimate. We compare our results to the experimental phase diagram recently obtained for an imbalanced Fermi gas at unitarity.

Further, we establish the phase diagram in the regime where the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state is the true ground state. The accurate treatment of thermal fluctuations allow us to identify the very low T_c of the amplitude modulated LO phase. The LO state is being characterized through its directly measurable magnetic structure factor and the temperature dependence of the density of states. The combination of spatial information and dynamical properties provides a comprehensive reference point for identifying FFLO correlations either in the solid state or cold atom lattices at strong coupling.

Further, the angle resolved spectral functions of a strong coupling Fermi gas in two dimensions in the presence of a Zeeman field is being studied. At zero field the global density of states show a pseudogap persisting to 2Tc . We observed that the magnetic field leads to the suppression of Tc, but an even quicker suppression of the pseudogap formation temperature. The full angle resolved spectrum is being computed, so as to identify the evolution of quasiparticle energies and damping across the thermal and field driven transitions.

A part of this period is being devoted in studying the physics of magnetic superconductors, wherein the possibility of the coexistence of magnetic and superconducting orders, as has been realized in certain superconducting materials, is being investigated through a two-dimensional attractive Hubbard model with Kondo interaction. Work in this direction is in progress.

Preprints:

1. Madhuparna Karmakar and Pinaki Majumdar, *Strong coupling s-wave superconductors in the extreme Pauli limit: I. The breached pair and metastable FFLO phases,* arXiv:1409.4025

2. Madhuparna Karmakar and Pinaki Majumdar, *Strong coupling s-wave superconductors in the extreme Pauli limit: II. Thermal signatures of FFLO correlations,* (in preparation).

3. Madhuparna Karmakar and Pinaki Majumdar, *Strong coupling s-wave superconductors in the extreme Pauli limit: III. Quasiparticle dynamics at finite temperature,* (in preparation).

Conference/Workshops Attended:

1. *The IX International Conference on Computational Physics (ICCP9)*, Singapore, January, 2015.

Academic recognition/Awards:

- Best Poster Award (ICCP9), 2015.

Debraj Rakshit

Research Summary:

During the academic year 2014-2015, I was interested in characterization of quantum correlations in many-body systems. Following are brief description of my works.

Spontaneous magnetization and critical scalings in random field Spin Systems. We investigate the effect of a symmetry breaking unidirectional quenched disorder on the magnetization of the system in *classical* spin models with continuous symmetry. We obtain the analytical expressions for the near-critical scalings of $SO(n)$ n-component spins. We report an interesting phenomenon called "order from disorder" in presence of an additional magnetic field. Recently, we have extended our analysis within the framework of quantum mechanics.

Beating no-go theorems by engineering defects in quantum spin models. The two-pronged restriction imposed by monogamy and translation invariance causes all two-qubit states of the ordered spin chains to be devoid of the quantum advantages. We propose that by using quenched disorder spin systems, it is possible to regain the quantum advantages while still retaining the translation invariance of the system, at least at the level of observables.

Adiabatic freezing of long-range quantum correlations in spin chains. We report a new phenomenon that we term as "adiabatic freezing of quantum correlation". We consider a process to create quasi long-range quantum discord between the non-interacting end spins of a quantum spin chain, with the end spins weakly coupled to the bulk of the chain. We find that the process is not only capable of creating long-range quantum correlation but the latter remains frozen, when certain weak end-couplings are adiabatically varied, provided they are below certain thresholds. This phenomenon is robust to moderate thermal fluctuations. We also find that the energy gap of the system can remain frozen for the adiabatic variations.

Enhancement of quantum correlation length in quenched disordered spin chains. In quantum spin systems, quantum entanglement decays exponentially with increasing lattice distance. However, Quantum discord, an information-theoretic quantum correlation measure, e, survives long lattice distances. We have investigated the effects of quenched disorder on quantum correlation lengths, viz., entanglement and quantum discord, in the anisotropic XY. We find that there is virtually neither reduction nor enhancement in entanglement length while quantum discord length may be increased significantly with the introduction of the quenched disorder

in certain parametric regime. Additionally, we study XYZ chain in order to find out the effect of an additional zz-interaction.
Quenched dynamics of quantum correlations. We study the dynamics of quantum correlations in a one-dimensional infinite quantum XY spin system caused by an instantaneous quench in the system Hamiltonian at zero temperature. We also consider the effect of thermal fluctuation on the system by monitoring the characterization of the entanglement at infinite time with increasing temperature.
characterization of multipartite entanglement properties for spin ladder system. We study the behavior of the scalings of genuine multipartite entanglement in these systems at zero temperature.

Publications:

1. Anindita Bera, Debraj Rakshit, Maciej Lewenstein, Aditi Sen(De), Ujjwal Sen, and Jan Wehr, *Classical spin models with broken symmetry: Random-field-induced order and persistence of spontaneous magnetization in the presence of a random field*, Phys. Rev. B **90, 174408 (2014)**.

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)**.

Preprints:

1. Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen *Adiabatic freezing of long-range quantum correlations in spin chains,* arXiv:1502.01489.

2. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, R. Prabhu, Aditi Sen(De), Ujjwal Sen *Enhancement of Quantum Correlation Length in Quenched Disordered Spin Chains,* arXiv:1503.04770.

3. Sudipto Singa Roy, Himadri Sekhar Dhar, Debraj Rakhsit, Aditi Sen(De), Ujjwal Sen *Diverging scaling with converging multisite entanglement in Heisenberg ladders,* (in preparation).

4. Anindita Bera, Debraj Rakshit, Maciej Lewenstein, Aditi Sen(De), Ujjwal Sen, and Jan Wehr, *Spontaneous Magnetization and Critical Scalings in Random Field Quantum Spin Systems,*(in preparation).

5. Utkarsh Mishra, Debraj Rakshit, and R. Prabhu *Quenched dynamics of quantum correlations in the non-equilibrium quantum XY spin model,* (in preparation).

Conference/Workshops Attended:

1. *One day QIC workshop* , HRI, November 2014.
   Presented a talk titled as *"Dynamics of entanglement and quantum discord in spin chains after a quench in coupling strength"*.

2. *School on Topological Quantum Matter*, HRI, February, 2015.
   Presented a poster titled as *"Adiabatic freezing of long-range quantum correlations in spin chains"*.

3. *Young Quantum-2015 (YouQu-15)*, HRI, India, February, 2015.
   Delivered a talk on *"Order from disorder and adiabatic freezing of quantum correlations in spin models with disorder"*.

Other Activities:

1. Organiser: *"Young Quantum - 2015 (YouQu-2015)"*, Harish-Chandra Research Institute, February, 2015.

Tanumoy Mandal

Research Summary:

During the last academic year, I have worked on various beyond the Standard Model (SM) scenarios including the phenomenology of anomalous Higgs couplings to weak bosons and prospects of heavy neutrino at future e^+e^- colliders and LHC phenomenology of first generation scalar leptoquarks.

In one project, we discuss the future prospects of heavy neutrino searches at next generation lepton colliders. We consider various production and decay modes of the heavy neutrino (N) and study a new production channel $e^+e^- \to Ne^\pm W^\mp$, which leads to a same-sign dilepton plus four jet final state, thus directly probing the lepton number violation in e^+e^- colliders. We use both cut-based and multivariate analysis techniques to make a realistic calculation of the relevant signal and background events, including detector effects for a generic linear collider detector.

In another project, we argue that in some cases, single production can contaminate pair production searches. Inclusion of model dependent single productions in pair production searches can give us new information about model parameters. Considering the example of the recent CMS search for first generation scalar leptoquark in the pair production channel, we illustrate how single productions can be systematically included in the signal estimations and demonstrate how it can affect the mass exclusion limits and give new bounds on leptoquark-lepton-quark couplings.

In another work, we have explored the phenomenology of anomalous HVV vertices ($V = W, Z, \gamma$) at an e^+e^- collider by adopting commonly used model-independent effective Lagrangian formalisms using a set of dimension-6 (6D) gauge invariant operators. This formalism modifies the HVV vertices by introducing non-standard momentum-dependent terms. We observe that the ratio of rates at two different energies, ratio of the s- and the t-channel Higgs production rates at fixed energies can potentially shed light on the anomalous behavior of the HVV couplings.

Publications:

1. Gilad Amar, Shankha Banerjee, Stefan von Buddenbrock, Alan S. Cornell, Tanumoy Mandal, Bruce Mellado, Biswarup Mukhopadhyaya, *Exploration of the Tensor Structure of the Higgs Boson Coupling to Weak Bosons in e^+e^- Collisions,* JHEP 1502 (2015) 128

2. Baradhwaj Coleppa, Tanumoy Mandal, Subhadip Mitra, *Coupling Extraction From Off-shell Cross-sections,* Phys. Rev. D 90, 055019 (2014)

Preprints:

1. Shankha Banerjee, P. S. Bhupal Dev, Alejandro Ibarra, Tanumoy Mandal, Manimala Mitra, *Prospects of Heavy Neutrino Searches at Future Lepton Colliders,* 1503.05491 [hep-ph]

2. Tanumoy Mandal, Subhadip Mitra, Satyajit Seth, *Single Productions of Colored Particles at the LHC: An Example with Scalar Leptoquarks,* 1503.04689 [hep-ph]

Visits to other Institutes:

1. Department of Physics, Cornell University, Ithaca, USA (20-26 November, 2014)

2. Department of Physics and Astronomy, University of California, Irvine, USA (16-19 November, 2014)

3. Department of Physics and Astronomy, California State University, Long Beach, USA (13-14 November, 2014)

4. Department of Physics, University of Florida, USA (10-12 November, 2014)

5. Department of Physics, Boston University, USA (5-7 November, 2014)

6. Department of Physics, University of Maryland, USA (2-4 November, 2014)

7. Department of Physics and Astronomy, University of Pittsburgh, USA (24-31 October, 2014)

8. Saha Institute of Nuclear Physics, Kolkata, India, June, 2014.

Invited Lectures/Seminars:

1. *"LHC Phenomenology of Exotic Fermions: Exploring Three-body Single Production"*, Department of Physics, Cornell University, Ithaca, USA (November 25, 2014).

2. *"LHC Phenomenology of Exotic Fermions: Exploring Three-body Single Production"*, Department of Physics and Astronomy, University of California, Irvine, USA (November 19, 2014).

3. *"Coupling Extraction from Off-shell Cross-sections"*, Department of Physics and Astronomy, California State University, Long Beach, USA (November 14, 2014).

4. *"LHC Phenomenology of Exotic Fermions: Exploring Three-body Single Production"*, Department of Physics, University of Florida, USA (November 12, 2014).

5. *"LHC Phenomenology of Exotic Fermions: Exploring Three-body Single Production"*, Department of Physics, Boston University, USA (November 6, 2014).

6. *"LHC Phenomenology of Exotic Fermions: Exploring Three-body Single Production"*, Department of Physics, University of Maryland, USA (November 3, 2014).

7. *"LHC Phenomenology of Exotic Fermions: Exploring Three-body Single Production"*, Department of Physics and Astronomy, University of Pittsburgh, USA (October 29, 2014).

8. *"A Novel Method of Coupling Extraction from Off-shell Cross-sections"*, Harish-Chandra Research Institute, Allahabad, India (September 22, 2014).

9. *"Phenomenology of Anomalous Higgs Couplings at an e^+e^- Collider"*, Harish-Chandra Research Institute, Allahabad, India (September 12, 2014).

10. *"Phenomenology and LHC Signatures of Exotic Fermions"*, Institute of Mathematical Sciences, Chennai, India (April 1, 2014).

Joint Colloquia

1. Jayanta K. Bhattacharjee: Patterns in Nature.
2. Siraz Minwalla: String Theory and Gauge-Gravity correspondence.
3. Shankar Ghosh: Friction induced organisation.
4. Sitabhra Sinha: Patterns of life and death: using physics to understand complex dynamics in human physiology.
5. Charles H Bennett: Boltzmann's Brain and Wigner's Friend.

Mathematics Talks and Seminars

1. W. Kohnen: Jacobi forms and their basic theory, Two classical applications: Saito-Kurokawa lift and growth estimates for Fourier coefficients of Siegel cusp forms, Two recent applications: characterization of siegel cusp forms by means of the growth of their Fourier coefficients and sign changes of Fourier cofficients of siegel cusp forms.
2. Eric Balandraud: The polynomial method and its applications in additive combinatorics.
3. R. Balasubramanian: Sidon sets.
4. Kuntal Banerjee: From circle Homeomorphisms to herman rings.
5. Rupam Barman : Hypergeometric functions over finite fields and p-adic numbers.
6. Steven Weintraub: A survey on arithmetic questions in the representation theory of finite groups.
7. Michel Nguiffo Boyom: The linearization problem for lagrangian webs in kaelerian maniflods with homogeneous Kaehler forms.
8. S. Boecherer: Siegel modular forms and their arithmetic.
9. Manish Mishra: The local langlands conjectures.
10. Bettina Wilkens: A short course on finite p-groups and their associated Lie rings.

Mathematics Colloquia

1. Kishore Marathe: Chem-Simons theory and link invariants.
2. Kishore Marathe: What is Physical Mathematics.
3. Winfried Kohnen: Eisenstein series.

Physics Talks and Seminars

1. R. Laha: Finding the minimum dark matter halo mass using indirect detection.
2. Sajeev Y: Ab initio many-body methods for electronic bound states coupled to the ionization continuum.
3. Sumathi Rao: Weyl fermions in condensed matter.
4. G. Adesso: Quantification of Gaussian quantum steering.
5. Bijan Saha: Cosmology with spinor field: Advantages and disadvantages.
6. S. Mondal: Connecting entanglement in quantum mechanics to entanglement in quantum field theory.
7. M. Honda: Exact results on ABJ theory and the refined topological string.
8. A. Jagannathan: Quantum models in quasicrystals.
9. J. Wudka: Phenomenology of effective theories.
10. Kush Saha: Phonon-induced topological insulation.
11. B. Danu: Studies on Frustrated Quantum antiferromagnets.
12. M. Murata: Current transport process through boundary states.
13. Lpganayagam. R.: entropy, eightfold way and Schwinger-Keldysh effective theory.
14. M. Verma: the holographic dictionary for beta functions of multi-trace coupling constants.
15. M. Honda: Supersymmetric index on $T^2 \times S^2$ and elliptic genus.

Physics Colloquia

1. G. Adesso: Quantifying quantum correlations.
2. G. Menon: Crowding: why it might not be a bad idea after all.
3. Swadesh Mahajan: An effective nonlinear quantum mechanics-a theory of Fluidons.
4. M. Sivakumar: Higher spin theories: past, present and Future.
5. R. Loganayagam: Gravitational Anomaly and fluid dynamics.
6. Diptiman Sen: Majorana fermions in one dimension.

Recent Graduates

1. **Pradip Kumar**, *Existence of Darboux Chart on Some Frchet Manifolds.*.
2. **Atri Bhattacharya**, *Probing Standard and Non-standard Physics with Ultra-High Energy Neutrinos*,
3. **Rajarshi Tiwari**, *The Effect of Geometric Frustration on some correlated Electron Systems*,
4. **K. Senthil Kumar**, *Liouville Fields, Mahler Fields and Schanuels Conjecture*,
5. **Arunabha Saha**, *Some Classical and Semiclassical Aspects of Higher Spin Theories in AdS3*,
6. **Ujjal kumar Dey**, *Some Studies on Minimal and Non-Minimal Universal Extra*.

Publications

Publications (Mathematics)

Sukumar Das Adhikari

1. Sukumar Das Adhikari, Weidong Gao and Guoqing Wang, *Erdős-Ginzburg-Ziv theorem for finite commutative semigroups,* Semigroup Forum, 88, Issue 3, 555–568, (2014).

2. Sukumar Das Adhikari and Eshita Mazumdar, *Modifications of some methods in the study of zero-sum constants,* Integers, 14, paper A 25, (2014).

3. Sukumar Das Adhikari and Yong-Gao Chen, *On monochromatic configurations for finite colorings*, Discrete Mathematics, Vol. 333, 106–109 (2014).

4. 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., To appear.

5. Sukumar Das Adhikari and Eshita Mazumdar, *The polynomial method in the study of zero-sum theorems,* Int. J. Number Theory, To appear.

Ramakrishnan B.

1. B. Ramakrishnan and Brundaban Sahu, *On the number of representations of an integer by certain quadratic forms in sixteen variables,* Int. J. Number Theory **10**, 1929–1937, (2014)

2. Soumya Das and B. Ramakrishnan, *Jacobi forms and differential operators,* J. Number Theory **149**, 351–367, (2015)

3. M. Manickam, Jaban Meher and B. Ramakrishnan, *Theory of newforms of half-integral weight,* Pacific J. Math. **274**, 125–139, (2015)

Kalyan Chakraborty

1. Kalyan Chakraborty and Jay Mehta, *Preventing unknown key-share attack using cryptographic bilinear maps,* Journal of Discrete Mathematical Sciences and Cryptography **17, No.2**, 135–147, (2014)

2. K. Chakraborty, S. Kanemitsu and T. Kuzumaki, *On the Barnes multiple gamma functions,* Šiauliai Mathematical Seminar **9, No. 17**, 27–41, (2014)

3. Kalyan Chakraborty and Makoto Minamide, *On Power moments Of The Hecke Multiplicative Functions,* J. Aust. Math. Soc. (First Published online 2015) doi: 10.1017/S1446788715000063, 1–7, (2015)

4. Kalyan Chakraborty, Shigeru Kanemitsu and Y. Sun, *Codons and Codes,* Pure and Applied Mathematics Journal **4; 2-1**, 25–29, (2015)

5. Tomihiro Arai, Kalyan Chakraborty and Jing Ma, *Applications of the Hurwitz-Lerch zeta-function,* Pure and Applied Mathematics Journal **4; 2-1**, 30–35, (2015)

D. Surya Ramana

1. P. Akhilesh and D.S. Ramana, *A Chromatic Version of Lagrange's Four Squares Theorem,* Monasthefte für Mathematik **176**, 17-29, (2015)

Hemangi Saha

(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.

Rukmini Dey

1. Indranil Biswas, Saikat Chatterjee, Rukmini Dey *Geometric prequantization on the path space of a prequantized manifold,* IJGMMP **vol 12, Issue 3**, page 1550030, (2015)

Ratnakumar Peetta Kandy

1. P. K. Ratnakumar, Vijay Kumar Sohani, *Non linear Schrödinger equation for the twisted Laplacian-Global wellposedness,* Mathematische Zeitschrift (to appear)

2. P. K. Ratnakumar. and Saurabh Kumar Shrivastava, *A remark on bilinear Littlewood-Paley square functions* Monatsh. Math. **176 , no. 4**, 615-622, (2015).

Chandan Singh Dalawat

1. *Classical reciprocity laws*, Asia Pacific Mathematics Newsletter, **4** (4), 5–9 ; cf. `arXiv:1406.1857`.

R. Thangadurai

1. R. Thangadurai and Pallab Kanti Dey, *The length of an arithmetic progression represented by a binary quadratic form*, Amer. Math. Monthly, **121** 932 - 936, (2014).

2. R. Thangadurai and S. Subburam, *On the Diophantine equation* $x^3 + by + 1 - xyz = 0$, C. R. Math. Acad. Sci. Soc. R. Can., **36**, 15-19 (2014).

3. R. Thangadurai and K. Viswanadham, *On the prime* k*-tuple conjecture*, Integers, **14** A28 (2014) 8pp.

4. R. Thangadurai and M. Ram Murty, *On the parity of the fourier coefficients of* j*-function*, Proc. Amer. Math. Soc. (Series A), **143**, 1391-1395 (2015).

Manoj Kumar

1. Pradeep K. Rai and Manoj K. Yadav, *On Ш-rigidity of groups of order* p^6, J. Algebra **428**, 26 - 42, (2015)

Punita Batra

1. Punita Batra and Hiroyuki Yamane, *Skew centers of rank-one generalized quantum groups, To appear in Toyama Mathematical Journal, Proceedings of Tsukuba Workshop on Infinite Dimensional Lie Theory and Related Topics, October 20-23, 2014.*

Satya Deo

1. Satya Deo, *Topological Colored Tverberg Theorem and the Reduction Lemma* , arXiv (Feb 2015)

2. Satya Deo and David Gauld, *Boundedly Metacompact or Finitistc Spaces and the Star Order of Covers,* J. Indian Math. Soc., to appear in (2015)

3. Satya Deo, *Colored Topological Tverberg Theorem of Blagojevic, Matschke and Ziegler,* Math Student, Accepted (2015).

Kasi Viswanadham G

1. Jay Mehta and G. K. Viswanadham, *Set of uniqueness of shifted Gaussian primes*, Funct. Approx. Comm. Math., To appear.

2. A. Mukhopadhyay, R. Thangadurai and G. K. Viswanadham, *Unique representation of integers with base A*, Arch. Math., To appear.

Jay Gopalbhai Mehta

1. Debika Banerjee and Jay Mehta, *Linearized product of two Riemann zeta functions*, Proc. Japan Acad. Ser. A Math. Sci. **90**, no. 8, 123-126, (2014).

2. Jay Mehta and G. K. Viswanadham, *Set of uniqueness of shifted Gaussian primes*, Funct. Approx. Comm. Math., To appear.

Pradeep Kumar Rai

1. P. K. Rai and M. K. Yadav, *On Ш-rigidity of groups of order p^6*, J. Algebra **428**, 26-42, (2015).

2. P. K. Rai, *On commuting automorphisms of finite p-groups,* Proc. Japan Acad. Ser. A Math. Sci. **91**, 57-60, (2015).

Akhilesh P

1. *A chromatic version of Lagranges four squares theorem*, P. Akhilesh, D. S. Ramana, Monatshefte für Mathematik , January 2015, Volume 176, Issue 1, pp 17-29.

Divyang G. Bhimani

1. D.G. Bhimani, *Contraction of functions in modulation spaces,* Integral Transforms Spec. Funct., http://dx.doi.org/10.1080/10652469.2015.1036055.

Eshita Mazumdar

1. Sukumar Das Adhikari, Eshita Mazumdar, *The polynomial method in the study of zero-sum theorems,* accepted to "International Journal of Number Theory".

Sneh Bala Sinha

1. Sneh Bala Sinha and Jaban Meher, *Some infinite sum identities.* Accepted, Czechoslovak Mathematical Journal.

Pallab Kanti Dey

1. Pallab Kanti Dey and R.Thangadurai, *The length of an arithmetic progression represented by a binary quadratic form,* Amer. Math. Monthly **121**, 932-936, (2014).

Publications (Physics)

Jayanta Kumar Bhattacharjee

1. H S Samanta, J K Bhattacharjee, A Bhattacharyay and S Chakrabarty, *On noise induced Poincare-Andronov-Hopf bifurcation* Chaos 24 043122 (2014)

2. H Pharasi, K Kumar and J K Bhattacharjee, *Frequency spectra in turbulent thermal convection with rotation* Phys Rev E90 041004 (R)

3. J K Bhattacharjee , *Kolmogorov argument for the scaling of the energy spectrum in a stratified fluid* Phys Lett A379 696 (2015)

4. D Das, D Banerjee and J K Bhattacharjee , *Finding limit cycles in self-excited oscillators with infinite series damping functions* Europhys J D69 85 (2015)

ARUN KUMAR PATI

1. L. Maccone and A. K. Pati,
   Stronger Uncertainty Relations for All Incompatible Observables,
   Phys. Rev. Lett. **113**, 260401 (2014).

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

Tapas Kumar Das

1. Das, T. K., Nag, S., Hegde, S., Bhattacharya, S., Maity, I., Czerny, B., Barai, P., Wiita, P. J., Karas, V., & Naskar, T., *Black hole spin dependence of general relativistic multi-transonic accretion close to the horizon,* New Astronomy **37**, 81 – 104, (2015)

2. Ananda, D. B., Bhattacharya, S., & Das, T. K., *Acoustic geometry through perturbation of mass accretion rate - radial flow in static spacetimes,* General Relativity and Gravitation **To appear**, (2015)

3. Tarafdar, P., & Das, T. K., *Dependence of acoustic surface gravity on geometric configuration of axisymmetric background matter flow in the*

Schwarzschild metric, International Journal of Modern Physics D **To appear** (2015)

4. Saha, S., Sen, S., Nag, S., Roychowdhury, S., & Das, T. K., *Model dependence of the multi-transonic behavior, stability properties and corresponding acoustic geometry for accretion onto a spinning black hole,* New Astronomy **To appear** (2015)

5. Ananda, D. B., Bhattacharya, S., & Das, T. K., *Emergent acoustic causality and stability analysis for axisymmetric flows through perturbation of mass accretion rate,* Classical & Quantum Gravity **Under review**, also at arXiv:1407.2268v3 [astro-ph.HE] (2014)

Aditi Sen De

1. T. Das, R. Prabhu, A. Sen(De), and U. Sen, *Multipartite Dense Coding vs. Quantum Correlation: Noise Inverts Relative Capability of Information Transfer,* Phys. Rev. A **90**, 022319 (2014)

2. A. D. Rane, U. Mishra, A. Biswas, A. Sen(De), and U. Sen, *Benford's law gives better scale exponents in phase transitions of quantum XY models,* Phys. Rev. E **90**, 022144 (2014)

3. A. Biswas, R. Prabhu, A. Sen(De) and U. Sen, *Genuine multipartite entanglement trends in gapless-to-gapped transitions of quantum spin systems,* Phys. Rev. A **90**, 032301 (2014)

4. Salini K., R. Prabhu, A. Sen(De), and U. Sen, *Monotonically increasing functions of any quantum correlation can make all multiparty states monogamous,* Ann. Phys. **348**, 297 (2014)

5. A. Bera, D. Rakshit, M. Lewenstein, A.Sen(De), U. Sen, and J. Wehr, *Classical spin models with broken symmetry: Random Field Induced Order and Persistence of spontaneous magnetization in presence of a random field,* Phys. Rev. B **90**, 174408 (2014)

6. U. Mishra, A. Sen(De), and U. Sen, *Local Decoherence-free Macroscopic Quantum states,* Phys. Lett. A **379**, 261 (2015)

7. A. Kumar, R. Prabhu, A. Sen(De), and U. Sen, *Do Large Number of Parties Enforce Monogamy in All Quantum Correlations?,* Phys. Rev. A **91**, 012341 (2015)

8. D. Sadhukhan, S. Singha 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).

9. A. Misra, A. Biswas, A.K. Pati, A. Sen(De), and U. Sen, *Quantum Correlation with Sandwiched Relative Entropies*, Phys. Rev. E (in print) (2015)

Raj Gandhi

1. Atri Bhattacharya (Arizona U.), Raj Gandhi (Harish-Chandra Res. Inst. and Fermilab), Aritra Gupta (Harish-Chandra Res. Inst.), *The Direct Detection of Boosted Dark Matter at High Energies and PeV events at IceCube* JCAP 1503 (2015) 03, 027

2. Animesh Chatterjee (Harish-Chandra Res. Inst.), K.K. Meghna (IMSc, Chennai), Kanishka Rawat (Panjab U., Chandigarh), Tarak Thakore (Tata Inst.), Vipin Bhatnagar (Panjab U., Chandigarh), R. Gandhi (Harish-Chandra Res. Inst.), D. Indumathi (IMSc, Chennai), N.K. Mondal (Tata Inst.), Nita Sinha (IMSc, Chennai), *A Simulations Study of the Muon Response of the Iron Calorimeter Detector at the India-based Neutrino Observatory* JINST 9 (2014) P07001

3. Animesh Chatterjee, Raj Gandhi (Harish-Chandra Res. Inst.), Jyotsna Singh (Lucknow U.), *Probing Lorentz and CPT Violation in a Magnetized Iron Detector using Atmospheric Neutrinos*, JHEP 1406 (2014) 045

4. Kalpana Bora (ed.) (Gauhati U.), D.P. Roy (ed.), Raj Gandhi (ed.), Dilip Kumar Chodhury (ed.), N. Nimai Singh (ed.), Nita Sinha (ed.), Madhurjya P. Bora (ed.), Anjan Ananda Sen *Proceedings, National Conference on Contemporary Issues in High Energy Physics and Cosmology*, J.Phys.Conf.Ser. 481 (2014)

Rajesh Gopakumar

1. M. R. Gaberdiel and R. Gopakumar, *Higher Spins and Strings*, JHEP **1411**, 044 (2014).

2. M. R. Gaberdiel and R. Gopakumar, *Stringy Symmetries and the Higher Spin Square*, J. Phys. A (To Appear) (2015)

Dileep P. Jatkar

1. Dileep P. Jatkar, Georgios Kofinas, Olivera Miskovic, Rodrigo Olea, *Conformal Mass in AdS gravity,* arXiv:1404.1411 [hep-th] **Phys.Rev. D89, 12, 124010 (2014)** .

2. Dileep P. Jatkar, Georgios Kofinas, Olivera Miskovic, Rodrigo Olea, *Conformal mass in Einstein-Gauss-Bonnet AdS gravity,* arXiv:1501.06861 [hep-th] **Phys.Rev. D91, 10, 105030 (2015)** .

AseshKrishna Datta

1. AseshKrishna Datta, Sabyasachi Chakraborty and Sourov Roy, $h \to \gamma\gamma$ *in* $U(1)_R$*-lepton number model with a right-handed neutrino* , JHEP **1502**, 124, (2015).

Anshuman Maharana

1. Koushik Dutta and Anshuman Maharana
   Inflationary Constraints on Modulus Dominated Cosmology
   Phys. Rev. D 91, 043503 (2015)

2. L. Aparicio, M. Cicoli, S. Krippendorf, A.Maharana, F. Muia and F. Quevedo; *Sequestered de Sitter String Scenarios: Soft-terms*
   JHEP 1411 (2014) 071

3. Michele Cicoli, Koushik Dutta and Anshuman Maharana
   N-flation with Hierarchically Light Axions in String Compactifications
   JHEP 1411 (2014) 071

Pinaki Majumdar

1. Anamitra Mukherjee and Pinaki Majumdar, *A real space description of magnetic field induced melting in the charge ordered manganites: I. The clean limit*, Eur. Phys. J. B, **87**, 238, (2014).

2. Anamitra Mukherjee and Pinaki Majumdar, *A real space description of magnetic field induced melting in the charge ordered manganites: II. The disordered case*, Eur. Phys. J. B, **87**, 239, (2014).

3. Sabyasachi Tarat and Pinaki Majumdar, *A real space auxiliary field approach to the BCS-BEC crossover,* Eur. Phys. J. B, **88**, 68, (2015).

4. Rajarshi Tiwari and Pinaki Majumdar, *Spectroscopic signatures of the Mott transition on the anisotropic triangular lattice,* Europhys. Lett, **108**, 27007, (2014).

Biswarup Mukhopadhyaya

1. Arindam Chatterjee, Debottam Das, Biswarup Mukhopadhyaya, Santosh Kumar Rai, *Right Sneutrino Dark Matter and a Monochromatic Photon Line,* JCAP **1407**, 023, (2014)

2. Aarti Girdhar, Biswarup Mukhopadhyaya, Monalisa Patra, *Distinguishing Signatures of top-and bottom-type heavy vectorlike quarks at the LHC ,* Phys. Rev. **D91**, 5-055015, (2015)

3. Gilad Amar, Shankha Banerjee, Stefan von Buddenbrock, Alan S. Cornell, Tanumoy Mandal, Bruce Mellado, Biswarup Mukhopadhyaya, *Exploration of the tensor structure of the Higgs boson coupling to weak bosons in e+ e— collisions,* JHEP **1502**, 128, (2015)

4. Nabarun Chakrabarty, Ujjal Kumar Dey, Biswarup Mukhopadhyaya, *High-scale validity of a two-Higgs doublet scenario: a study including LHC data,* JHEP **1412**, 166, (2014)

5. Nabarun Chakrabarty, Tao Han, Zhen Liu, Biswarup Mukhopadhyaya, *Radiative Return for Heavy Higgs Boson at a Muon Collider,* Phys. Rev. **D91**, 1-015009, (2015)

6. Nabarun Chakrabarty, Ujjal Kumar Dey, Biswarup Mukhopadhyaya, *High-scale validity of a two-Higgs doublet scenario: a study including LHC data,* JHEP **1412**, 166, (2014)

7. Satyaki Bhattachaeya, Mariana Frank, Katri Huitu, Ushoshi Maitra, Biswarup Mukhopadhyaya, Santosh Kumar Rai, *Probing the light radion through diphotons at the Large Hadron Collider,* Phys. Rev. **D91**, 016008, (2014)

8. Ashmita Das, Biswarup Mukhopadhyaya, Soumitra SenGupta, *Why has spacetime torsion such negligible effect on the Universe?,* Phys. Rev. **D90**, 10-107901, (2014)

9. Arindam Chatterjee, Arghya Choudhury, Amitava Datta, Biswarup Mukhopadhyaya, *Gluino mass limits with sbottom NLSP in coannihilation scenarios,* JHEP. **D1501**, 154, (2015)

10. Avinanda Chaudhuri, Najimuddin Khan, Biswarup Mukhopadhyaya, Subhendu Rakshit, *Dark matter candidate in an extended type III seesaw scenario ,* Phys. Rev. **D91**, 055024, (2015)

Ujjwal Sen

1. L. Jindal, A.D. Rane, H.S. Dhar, A. Sen(De), and U. Sen, *Patterns of Genuine Multipartite Entanglement in Frustrated Quantum Spin Systems,* Phys. Rev. A **89**, 012316 (2014)

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About the Computer Section

1. Scientific Software; Mathematica and Matlab were upgraded with the latest versions.
2. Desktop Computers of the Faculty, Students, Post-Doctoral Fellows and Visiting Fellows were upgraded with the latest version of Linux Operating Systems.
3. Latest version of several application software and packages were loaded on systems of users/computer centre/conference room that enabled the researchers to compute the numerical and analytical calculations faster and precise manner.
4. All the important packages in the systems 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.
5. Adequate computing support was provided to participants of the conferences.
6. 30 new desktop computers were purchased for Ph.D. students.
7. Up-gradation of the entire campus-wide network with Gigabit fibre backbone to increase accessibility, speed, and the reliability was completed.
8. Replacement of old SMF batteries with the new SMF batteries for the centralised online UPS systems were completed.

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 purchase high end rack servers with large storage to cater the present need of the academic and administrative staff.
3. It is planned to purchase 11 Desktops for the Ph.D. students.
4. It is planned to purchase a colour printer for the computer centre users.

Library

The Institutes 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 academic and research activities. It remains open on all working days from 8:00 am to 2:00 am including Saturdays. It also remains open during the Sundays and the Gazzetted holidays from 10:00 a.m. to 6:00 p.m. It has added 366(Three hundred sixty six) books including 43 gifted books to its fold. It increased the total number of books to 21520 (Twenty one thousand five hundred and twenty) which includes 1120 gifted books. It has also added 503 bound volumes of the journals during the period from 1st April 2014 to 31st March 2015. It has increased its bound volume collection to 35923. The institutes library has a total collection of 57443 (Fifty seven thousand and four hundred forty three) books and bound volumes. The library had subscribed to 178 journals during this period. This includes 96 online journals.
During the current year we have procured or added the Archives of Springer E-Books archives in 'Lecture notes In Mathematics' too in our collection.
The physical stock verification was recently completed with the help of PDT (Portable Data Terminal) for collection of Bar Codes. The whole collection is Bar Coded and equipped with Tattle Tapes for security. It reflected no loss of any title in the category of books or journals.
Our library is facing a lot of space problem. As we know that the library is a growing organism the need for space is increasing accordingly. We had already planned for 2.5 folds increase to our present space. The construction of the same is also in the full swing which would have allowed the library space increase horizontally but due to legal issues it has been stopped. Recently, we are in process of enriching our Library with RFID solutions for better library services. We enriched our Digital Library Depository 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 the Video lectures and other useful links. The emphasis was to procure maximum number of journals on line. We have been providing on-line access of periodicals to our users for 96 (Ninety six) titles.
We have provided the Web Enabled library catalogue to our users. The library is aiming to be termed as a Completely Automated Library System. The online catalogue has increased the opportunities of the use of our library resources by the neighboring organisations such as INSDOC, TIFR

etc. through the Document Delivery Services (DDS). Normally we provide the DDS on request through post, at a very nominal cost, but requests have also been honoured through e-mails. We had encouraged the use of the library by providing library consultation facilities to research scholars from neighboring institutes. We had strengthened our library security with the implementation of Electro-magnetic Tattle Tapes to reduce losses.

Construction Activity

Activities related to building construction work from February-2013 was affected due to order of Hon'ble High court, Allahabad in regard to PIL no. 4003 of 2006 related to Ganga pollution. The Hon'ble High court has passed an order that no construction shall be carried out within 500 meters of High Flood Level (HFL) of river Ganges in the year 1978. According to that, HRI falls within this prohibited zone. 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 is our case is still awaited therefore since last two years major construction activity is almost stopped.
Some miscellaneous works related maintenance/modifications were carried out during this financial year:-

- Replacement of one no. 8 passenger Hydraulic lift with 6 or 8 passenger machine room less lift in existing shaft area of institute building.
- Up-gradation of electrical power cables connectivity in some of old housing areas and enhancement of security light at boundary wall.
- Development of area near new married apartment (PDF housing).
- Separate reading Zone for Library users.
- Supply and installation of one no. projector for Auditorium.