Academic Report – 2012–13

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 has been named as a new Director of the Institute. 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. Among them are Ashoke Sen, A. Raychaudhuri, B. Mukhopadhyaya, Pinaki Majumdar, Rajesh Gopakumar are all winners of the prestigious S. S. Bhatnagar award. Ashoke Sen was also awarded the Padmashri, was elected to the Fellowship of the Royal Society and the prestigious Infosys prize in 2009. Prof. Rajesh Gopakumar had earlier won the Swarnajayanti fellowship of Department of Science and Technology and the International Centre for Theoretical Physics (ICTP) prize for 2006. Prof. Ashoke Sen was chosen for the First Fundamental Physics Prize 2012 by Yuri Milner and the coveted Padma Bhushan Award in 2013.

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 the cosmic microwave background, large scale structure formation and galaxy evolution. 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 the-

ory, 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

Even by the rather high standards of HRI, 2012-2013 was an exceptional year. Prof Ashoke Sen was among the first nine recipients of the newly instituted "Fundamental Physics Prize" in July 2012. This prize funded by the Russian entrepreneur Yuri Milner honours theorists who have made absolutely outstanding contributions. It recognizes the fact that the Nobel prize which is considered the biggest recognition, is often not a viable option for the theorist. This is because unless there is experimental corroboration, a theorist's contribution is generally sidelined and often there is a long gap between a prediction and its experimental realization. In the case of Bose Einstein condensation this gap was about 75 years, for the Higgs boson about 50! So it is necessary to have a different yardstick for the theorist and thus the first installment of this award recognized theorists who are literally household names and Prof Sen was among this set of theorists. In the beginning of 2013, Prof Arun Pati of the newly constituted quantum information group of HRI was elected fellow of the Indian Academy of Sciences, Bangalore and as the republic day came along , the Government of India bestowed the Padma Bhushan award to Prof Ashoke Sen, completing a dream year for HRI so far as recognitions go.

Academic activities remained as vibrant as ever with important publications in physics and mathematics. The increasing number of students and post doctoral fellows from across the country and across the world is an adequate testimony to the regard in which HRI is held in the academic community. The number of short term visitors also keeps on increasing every year and is an excellent indicator of the standing of HRI. With the admissions in the post BSc and post MSc programmes this year, the number of students has crept up quite close to the three figure mark. The Triveni lecture for the year was given in December 2012 by Prof Klaus Von Klitzing of the Max Planck Institute for Solid State Research in Stuttgart, Germany. Prof Klitzing, who discovered the quantum Hall effect spoke on "News from Quantum Hall Physics". The Giridharilal lecture for the year was also held in Dec 2012 and was delivered by Prof Fernando Quevedo who is currently the director of ICTP,Trieste. He spoke on "The large Hadron Collider, our Universe and String Theory". The winter months , this year, were dominated by the 8 week-long maha kumbh celebrations just outside the institute boundary and hence prevented the holding of large scale conferences /schools which are the norm for this time of the year. A short instructional school in high energy physics was held in March 2013. The INSA S.N. Bose lecture was arranged in HRI and the lecturer was Prof

S M Roy, formerly of TIFR. In summer the SPIM (Summer program in mathematics) program was conducted as usual. This program for college students which exposes them to learning mathematics by thought and reason is extremely popular and draws students from neighbouring countries as well. The visiting student program (VSP) for physics students (undergraduates primarily) has been so popular that it has been introduced at other times of the year, apart from the usual summer months. A week long science program in Hindi has also been conducted, as usual, to help local students get a real feel for scientific logic.

As in other years, HRI conducted Science Talent Tests in mathematics and physics for school students in the Allahabad area. Students of 10th and 12th grade from various schools in Allahabad appeared for this test. The toppers were awarded prizes in a special function organized in HRI, which this year was held on February 20, 2013. The chief guest for the occasion was Prof Rupamanjari Ghosh of JNU, presently the vice chancellor of SMU, who gave a popular lecture on light and lasers.

On the construction front the year started with a bang but ended with a whimper. Thanks to a huge amount of effort put in by the engineering section, the engineering building and the extension of the community centre could be inaugurated by the DAE secretary and AEC chairman Prof. Ratan Sinha in August 2012. The married students quarters were as nearly ready as possible by the end of 2012. The work on the six storey student hostel was progressing at a rapid rate and was headed for providing at least a partial occupation to the students who entered in 2013. The contract for constructing an extension to the guest house and a state of the art conference centre was given to DCSEM. When things were really looking up on this front, all construction had to be halted by an order passed by the Allahabad High Court in a public interest litigation of 2006 about the pollution of Ganga. This order prohibits any construction within 500 metres of the bank of the river. The stalemate in construction persists as this report is written.

In the quest to improve the scientific infrastructure, HRI has recently installed a 50-node parallel cluster with high speed interconnect. The benchmarks indicate that it is currently the 22nd fastest supercomputer in India. It will be used for solving problems in materials theory, quantum information and high energy physics.

This year has also been marked by the visit of several high profile visitors on the administration front. In August 2012, the DAE secretary visited HRI to felicitate Prof. Sen on his receiving the "Fundamental Physics Prize".

In January 2013, the parliamentary standing committee for science and technology, environment and forests, visited HRI and interacted with the faculty members in a friendly and open environment. In February 2013, the Member, Finance of DAE visited HRI and had a long discussion with the faculty members.

There have been some changes on the personnel front. Dr. Tirthankar Roy Choudhury has resigned to stay on in NCRA, Pune. Prof. Ravindran has been given lien to join IMSc., Chennai. Dr. Santosh Rai and Dr. Anshuman Maharana have joined the physics faculty while Dr. Hemangi Shah is expected to join the maths faculty soon. Mr. K.S. Shukla of the library has retired in the course of the year.

Jayanta Kumar Bhattacharjee

List of Governing Council Members

(2011 -12)

1. Prof. M. S. Raghunathan
   (Chairman, Governing Council HRI)
   School of Mathematics
   Tata Institute of Fundamental Research
   Homi Bhabha Road,
   MUMBAI - 400 005

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

3. Shri V. R. Sadasivam
   Joint Secretary (F) DAE
   Govt. of India,
   Chhatrapati Shivaji Maharaj Marg,
   MUMBAI - 400 001

4. Mr. Pradeep R. Baviskar
   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. Narendra Kumar
   Raman Research Institute
   C.V. Raman Avenue,
   Sadashivanagar
   Bangalore - 560 080

7. Prof. H. S. Mani
   2, Fourth Cross Street

Durga Colony, Sembakkam
CHENNAI - 600 073

8. Dr. J. D. Mitra
Director, 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. Shri 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 (Ex. Officio)
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

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. V. Ravindran
11. Prof. Rajesh Gopakumar
12. Dr. T. P. Pareek
13. Dr. Prasenjit Sen
14. Dr. Tapas Kumar Das
15. Dr. Aseshkrishna Datta
16. Dr. Sandhya Choubey
17. Dr. Ujjwal Sen
18. Dr. Aditi Sen De
19. Dr. G.Venketeswara Pai
20. Dr. Arun Kumar Pati
21. Dr. Anirban Basu
22. Dr. Santosh Kumar Rai
23. 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 Prabhat Kumar [Senior Private Secretary]
8. Shri A.K. Srivastava [SO (SB) (Electrical)]
9. Shri V.K. Srivastava [SO (SB) (Civil)]
10. Shri Jagannath Yadav [Accountant]
11. Shri R.P. Sharma [Manager Guest House]
12. Ms. Archana Tandon [Office Superintendent]
13. Ms. Anju Verma [Scientific Assistant]
14. Shri U.K. Dwivedi [Cashier]
15. Shri D. Malhotra [Upper Division Clerk]
16. Shri K.K. Srivastava [Upper Division Clerk]
17. Shri Yashpal Singh [Stenographer]
18. Ms. Sumitra [Upper Division Clerk]
19. Ms. Seema Agarwal [Receptionist]
20. Mr. Om Kumar Karn [Junior Hindi Translator]
21. Shri Umesh Kumar Singh [Store/Purchase Officer]
22. Shri P.N. Mishra [Jr. Lib. Assistant]
23. Shri D.P. Sharma [Jr. Lib. Assistant]

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

Visiting Fellow

Mathematics

1. Dr. Ashwin S. Pande
2. Dr. Surjeet Kour
3. Mr. Sachin Subhash Sharma

Physics

1. Dr. Efgnwande Osoba
2. Dr. Satoshi Ohya
3. Dr. Itzadah Thongkool
4. Dr. Binata Panda
5. Dr. Masahide Manabe
6. Dr. Sourav Bhattacharya
7. Dr. Kenji Nishiwaki
8. Dr. Kouhei Hasegawa
9. Dr. Anindya Biswas
10. Dr. Manabendra Nath Bera
11. Dr. Abhinav Saket
12. Dr. Richard Garavuso
13. Dr. Yoshinori Homma
14. Dr. Madhuparna Karmakar
15. Dr. Arindam Chatterjee
16. Dr. Ambresh Kumar Shivaji
17. Shri Trilochan Bagarti

Visiting Scientist

1. Prof. Satya Deo (Maths)
2. Dr. Prabhu R. (INSPIRE Faculty)
3. Dr. Matan Field (Physics)

Research Scholar

Mathematics

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

Physics

1. Mr. Ram Lal Awasthi
2. Mr. Atri Bhattacharya
3. Mr. Manoj Kumar Mandal
4. Mr. Saurabh Niyogi
5. Mr. Arunabha Saha
6. Mr. Ujjal Kumar Dey
7. Mr. Saurabh Pradhan
8. Mr. Vikas Chauhan
9. Mr. Sourav Mitra
10. Mr. Sabyasachi Tarat
11. Mr. Nyayabanta Swain
12. Mr. Abhishek Chowdhury
13. Mr. Swapnamay Mondal
14. Ms. Akansha Singh
15. Ms. Shrobona Bagchi
16. Mr. Mehedi Masud
17. Mr. Avijit Misra
18. Mr. Narayan Rana
19. Mr. Maguni Mahakhud
20. Ms. Avinanda Chaudhuri
21. Mr. Utkarsh Mishra
22. Ms. Ushoshi Maitra
23. Mr. Udit Narayan Chawdhury
24. Mr. Roji Pius

25. Mr. Taushif Ahmed
26. Mr. Aritra Gupta
27. Mr. Abhishek Joshi
28. Mr. Shankha Banerjee
29. Mr. Uttam Singh
30. Mr. Kadge Samrat Suresh
31. Mr. Dibya Kanti Mukherjee
32. Mr. Arijit Dutta
33. Mr. Soumyadeep Chaudhuri
34. Mr. Sauri Bhattacharya
35. Mr. Saikat Banerjee
36. Mr. Tamoghna Das
37. Mr. Krashna Mohan Tripathi
38. Mr. Asutosh Kumar
39. Mr. Debasis Mondal
40. Mr. Ashis Kumar Pal
41. Mr. Nabarun Chakrabarty
42. Mr. Aditya Banerjee
43. Mr. Udit Khanna
44. Mr. Ali Sarosh Ansar
45. Mr. Alok Kumar Sinha
46. Ms. Ajanta Maity
47. Mr. Harshant Singh
48. Mr. Debasis Sadhukhan
49. Mr. Sudipto Singha Roy

50. Mr. Mritunjay Kumar Verma
51. Mr. Sitender Pratap Kashyap
52. Ms. Juhi Dutta
53. Mr. Titas Chanda
54. Mr. Ankur Das
55. Mr. Subhroneel Chakrabarti
56. Mr. Satadal Datta
57. Mr. Jyotiranjan B.
58. Mr. Kasinath Das
59. Mr. Rishu Kumar Singh
60. Ms. Ruchi Saxena
61. Md. Arif Shaikh
62. Mr. Siddharth Dwivedi

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. Work is also going on some problems related to monochromatic configurations for any finite coloring of the Euclidean plane.

Publications:

1. Sukumar Das Adhikari and Purusottam Rath, *Remarks on monochromatic configurations for finite colorings of the plane,* Note di Matematica, **32**, no. 2, 83 –88 (2012).

2. Sukumar Das Adhikari, *An extremal problem in combinatorial number theory*, Proceedings of he Legacy of Srinivasa Ramanujan Conference held in Delhi during Dec 17-22, 2012, (to appear).

Conference/Workshops Attended:

1. *Additive Combinatorics*, held at HRI, Allahabad, 18-30 May, 2012.

2. *ISL (Instructional school for lecturers) Combinatorics*, held at HRI, Allahabad, 1-14 June, 2012.

3. *Additive Combinatorics in Paris*, 9-13 July, 2012.

4. *'Almora Mathematical Surveys'*, at Centre for Excellance in Mathematical Sciences, Kumaun Universiry, Almora, 3-6 October, 2012.

5. *26th Annual Conference of Ramanujan Mathematical Society*, held at Delhi, hosted by Shiv Nadar University, 20-23 October, 2012.

6. *Conference in Number Theory*, Department of Mathematics, Jadavpur University, Kolkata, 12 - 13 December, 2012.

7. *International Conference 'Legacy of Srinivasa Ramanujan'*, at Srinivasa Ramanujan Center, SASTRA University, Kumbakonam, 14 - 15 December, 2012.

8. *International Conference 'The legacy of Srinivasa Ramanujan'*, at University of Delhi, 17 - 22 December, 2012.

9. *International Conference on Dynamical System and Ergodic Theory,* at the Department of Mathematics, M.S. University of Baroda, Vadodara, 26 - 29 December, 2012.

10. *The 78th Annual Conference of Indian Mathematical Society,* held at Banaras Hindu University, 22-25 January, 2013.

11. *National seminar on recent trends in Mathematics (NSRTM-2013)*, at Department of Mathematics, University of Kalyani, West Bengal, 7th March, 2013.

Visits to other Institutes:

1. Nanjing University, China, 6 - 11 April, 2012.

2. Nanjing Normal University, China, 12 - 17 April, 2012.

3. South China Normal University, Guangzhou, China, 18 - 24 April, 2012.

4. Department of Mathematics, the University of Hong Kong, 25 - 27 April, 2012.

5. Mathematics department of University of Lille 1, France, 27-30 June, 2012.

6. Department of Mathematics, Karl-Franzens University, Graz, Austria, July 1 - 8, 2012.

7. Goa University, India, December 10, 2012.

8. Indian Statistical Institute, New Delhi, India, February 5-8, 2013.

9. Ramakrishna Mission Vivekananda University, Belur, India, February and March 2013.

Invited Lectures/Seminars:

1. *The Davenport constant with weights and related questions*, Seminar, Karl-Franzens University, Graz, Austria, 5 th July, 2012

2. *Some weighted zero-sum problems*, Invited talk, Additive Combinatorics in Paris, 9th–13th July, 2012.

3. *Algebraic methods in Additive Combinatorics*, Invited talk, Almora Mathematical Surveys, Centre for Excellance in Mathematical Sciences, Kumaun Universiry, Almora, 3rd-6th October, 2012.

4. *Ramsey-type theorems in the plane*, Invited talk, Symposium on Combinatorics in the Annual Conference of the Ramanujan Mathematical Society, held at Delhi, hosted by Shiv Nadar University, Oct 20-23, 2012.

5. *Two early Ramsey-type theorems and some early generalizations*, Invited talk, Conference in Number Theory, Department of Mathematics, Jadavpur University, Kolkata, 12 - 14, 2012.

6. *Some arithmetical functions and some problems regarding visibility of integer lattice points*, Invited talk, International Conference 'Legacy of Srinivasa Ramanujan' at Srinivasa Ramanujan Center, SASTRA University, Kumbakonam, 14th - 15th December, 2012.

7. *An extremal problem in combinatorial number theory*, Invited talk, International Conference 'The legacy of Srinivasa Ramanujan', University of Delhi, 17-22 December, 2012.

8. *Some early Ramsey-type theorems in Combinatorial Number Theory: Some generalizations and open questions*, Invited talk, The 78th Annual Conference of Indian Mathematical Society, held at Banaras Hindu University, January 22-25, 2013.

9. *A classical zero-sum theorem and some generalizations*, Seminar, ISI, Delhi, February 6, 2013.

10. *Some problems regarding visibility of integer lattice points*, Invited talk, National seminar on recent trends in Mathematics (NSRTM-2013), Department of Mathematics, University of Kalyani, March 7th 2013.

Academic recognition/Awards:

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

Other Activities:

- Currently suprvising two Ph. D. students.

- Currently working as a member of 'the National Board for Higher Mathematics' (NBHM).
- Working as a member of the editorial board of the periodical 'Mathematics Newsletter' published by Ramanujan Mathematical Society.
- Gave a course of lectures at a meeting on 'Additive Combinatorics' at HRI in May, 2012.
- Was one of the conveners of ISL (Instructional school for lecturers) Combinatorics, held at HRI during 1-14 June, 2012 and gave a course of 7 lectures in this school.
- Gave a course of lectures on number theory to the M. Sc. students at Ramakrishna Mission Vivekananda University, Belur, in Feb-March, 2013.

Ramakrishnan B

Research Summary:

1. Evaluation of the convolution sums of the divisor functions and an application (joint work with Brundaban Sahu): We evaluate the convolution sums $\sum_{l,m\in\mathbf{N},l+15m=n}\sigma(l)\sigma(m)$ and $\sum_{l,m\in\mathbf{N},3l+5m=n}\sigma(l)\sigma(m)$ for all $n\in\mathbf{N}$ using the theory of quasimodular forms and use these convolution sums to determine the number of representations of a positive integer n by the form

$$x_1^2+x_1x_2+x_2^2+x_3^2+x_3x_4+x_4^2+5(x_5^2+x_5x_6+x_6^2+x_7^2+x_7x_8+x_8^2).$$

We also determine the number of representations of positive integers by the quadratic form

$$x_1^2+x_2^2+x_3^2+x_4^2+6(x_5^2+x_6^2+x_7^2+x_8^2),$$

by using the convolution sums obtained earlier by A. Alaca, S. Alaca and K. S. Williams.

2. On a correspondence between Jacobi cusp forms and elliptic cusp forms (joint work with Karam Deo Shankhadhar): In this work, we prove a generalization of a correspondence between holomorphic Jacobi cusp forms of higher degree (matrix index) and elliptic cusp forms obtained by K. Bringmann [Math. Z. **252** (2006)], for forms of higher levels (for congruence subgroups). To achieve this, we make use of the method adopted by M. Manickam and B. Ramakrishnan [Trans. Amer. Math. Soc. **352** (2000)], who obtained similar correspondence in the degree one case. We also derive a similar correspondence in the case of skew-holomorphic Jacobi forms (matrix index and for congruence subgroups). Such results in the degree one case (for the full group) were obtained by N. -P. Skoruppa and also by M. Manickam.

3. Identities for the Ramanujan Tau Function and Certain convolution sum identities for the divisor functions (joint work with Brundaban Sahu): We give a list of identities for the Ramanujan tau function. As consequences, we obtain congruences for the tau function and further derive convolution sums and congruence relations involving the divisor functions.

4. A property of Jacobi forms of weight 2 (joint with Soumya Das): We partially prove a conjecture of S. Böcherer concerning the feasibility of removing one differential operator from the standard collection of $m+1$ of

them used to embed the space of Jacobi forms of weight 2 and index m into several pieces of elliptic modular forms.

5. Convolution sums of the divisor functions (joint work with Brundaban Sahu): We continue our earlier work described in [1] of evaluating convolution sums of the divisor functions and as an application, we find formulas for the number of representations of a positive integer by certain quadratic forms. This work is in progress.

6. Jacobi Eisenstein series of lattice index (joint with M. Manickam and N. -P. Skoruppa): We describe a simple method for constructing Jacobi forms of arbitrary lattice index. We apply this method for obtaining explicit formulas for the Fourier coefficients of Jacobi forms of arbitrary lattice index. The work is in progress.

Publications:

1. B. Ramakrishnan and Brundaban Sahu, *Evaluation of the convolution sums $\sum_{l+15m=n}\sigma(l)\sigma(m)$ and $\sum_{3l+5m=n}\sigma(l)\sigma(m)$ and an application*, International Journal of Number Theory **9**, 799–809 (2013)

Preprints:

1. B. Ramakrishnan and Karam Deo Shankhadhar, *On a correspondence between Jacobi cusp forms and elliptic cusp forms*, Accepted for publication.

2. B. Ramakrishnan and Brundaban Sahu, *Identities for the Ramanujan Tau Function and Certain convolution sum identities for the divisor functions*, Submitted.

3. Soumya Das and B. Ramakrishnan *A property of Jacobi forms of weight 2*, Submitted.

Conference/Workshops Attended:

1. *Workshop on Modular Forms, Kerala School of Mathematics, Kozhikode, Kerala* October 2012.

2. *International Conference on The Legacy of Srinivasa Ramanujan, University of Delhi, New Delhi* December 2012.

Visits to other Institutes:

1. The Abdus Salam ICTP, Trieste, Italy, April–June 2012 (two months).
2. The Institute of Mathematical Sciences, Chennai, August 2012 (one week).

Invited Lectures/Seminars:

1. *Theta series, L-functions*, Workshop on Modular Forms, KSOM, Kozikode, Kerala, October 2012.
2. *Modular Correspondences*, The Legacy of Srinivasa Ramanujan, New Delhi, December 2012.

Other Activities:

1. Supervised a PhD student at HRI who has submitted his thesis during this year.
2. Coordinator of the Talent Search Examination (Mathematics) for school children conducted by HRI during November 2012.
3. Mentoring two first year research students at HRI for their seminar course.

Punita Batra

Research Summary:

Let $q = (q_{ij})$ be a $d \times d$ complex matrix satisfying $q_{ii} = 1, q_{ij} = {q_{ji}}^{-1}$ with all q_{ij} being roots of unity. In a joint work with S.Eswara Rao and Sachin S. Sharma, we consider the quantum torus $\mathbb{C}_q$ associated with q and its deivation algebra $Der(\mathbb{C}_q)$. We have classified irreducible modules with finite dimensional weight spaces for the Lie Algebra $Der(\mathbb{C}_q) \propto \mathbb{C}_q$. These modules turn out to be of the form $V \otimes \mathbb{C}_q$, where V is a finite dimensional irreducible gl_d-module.

Preprints:

1. S. Eswara Rao, Punita Batra and Sachin S. Sharma, *The irreducible modules for the derivations of the rational quantum torus,* submitted for publication.

Conference/Workshops Attended:

1. *78th Annual Conference of the Indian Mathematical Society,* BHU, Varanasi, January 23-24, 2013.

Visits to other Institutes:

1. BHU, Varanasi during January 23-24, 2013.

Other Activities:

1. Gave two lectures in the Rajbhasha scientific workshop at HRI in May 2012.
2. Gave six lectures on " Galois Theory" in Summer Programme in Mathematics(SPIM) at HRI in June, 2012.
3. Advised one student from IISER Mohali on "Lie algebra and Representation Theory" project for one month during May/June 2012.
4. Organised a Lie Theory Symposium at the 78th Annual Conference of the Indian Mathematical Society at BHU on January 24, 2013.
5. Refereed Sachin Sharma's Ph.D thesis in March 2013.

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

D Surya Ramana

Research Summary:

Work in progress involves obtaining a sharp answer to the following combinatorial problem : given a finite product $\prod_{i\in I} X_i$ of finite sets X_i. subsets A, B of this product and a subset J of I, determine bounds for the number of pairs $(a, b) \in A \times B$ such that $a_i \neq b_i$ for all $i \in J$, where the a_i and b_i are co-ordinates of index i of a and b, respectively. This problem has applications to the question of obtaining optimal upper bounds for the number of solutions to the equation $x_1 + x_2 = x_3 + x_4$ with each x_i belonging to a given set S of prime numbers in an interval $(N, 2N]$. This number is called the additive energy of S and plays a key role in the study of additive representation of integers by elements of S.

Together with my research students, we are looking at the possibility of extending our work, with O. Ramaré, on monochromatic sums of primes to the sequence of squares (P. Akhilesh) and that of refining the pointwise bounds of Heath-Brown for the absolute value of the Dedekind zeta functions on the critical line (Kasi Viswanadham).

Publications:

1. P. Akhilesh and D.S. Ramana, *A Remark on the Selberg-Beurling function,* Acta Math. Hungarica **139**, 354-362, (2013)

2. D.S. Ramana and O. Ramarè, *Additive Energy of Dense Sets of Primes and Monochromatic Representation,* Israel Journal of Mathematics, to appear.

Preprints:

1. D.S. Ramana, *A Bound for the Additive Energy of Dense Sets of Primes,* Submitted to Proceedings of the Conference Legacy of Ramanujan, December 2013.

2. S.D. Adhikari and D. S. Ramana, *Some Omega Results and Connected Questions related to R. Balasubramanian's mathematical work,* Submitted to Proceedings of the International Conference on Number Theory, HRI, 2011.

Conference/Workshops Attended:

1. *Legacy of Ramanujan*, New Delhi, December 2012.
2. *Ramanujan Math. Society Annual Conference*, New Delhi, October 2012.

Visits to other Institutes:

1. University of Paris VI, France, 10 September - 10 October, 2012.
2. Universitidad Autonoma Madrid, September 2012.

Invited Lectures/Seminars:

1. *The Hardy-Ramanujan Formula for the Partition Function*, Ramanujan Math. Society Annual Meeting, New Delhi, December 2012.
2. *Additive Energy of Dense Sets of Primes and Monochromatic Representation*, Rencontres de thorie analytique des nombres, Institut Henri Poincaré, Paris, September 2012.

Other Activities:

1. Taught the course Algebra II from January to May, 2013 as a part of the HRI Graduate Programme.
2. Convenor, Graduate Programme Committee (Mathematics), HRI.
3. Member, Local Works Committee, HRI and Invitee to Building Works Committee, HRI.

Kalyan Chakraborty

Research Summary:

In a joint work with Makoto Minamide, we are working on generalizing a result of K. Soundararajan regarding the sum of the k-th power of the absolute value of Hecke-multiplicative functions, e.g Maass forms. The case $k = 2$ (Soundararajan's case) was an important step of Soundararajan's recent proof of the Quantum Unique Ergodicity for $SL_2(\mathbb{Z})$.

Along with my other collaborators Profs. Kanemitsu and Kuzumaki, I am continuing my study of multiple zeta and gamma functions. We are also into a project of looking into various applications of the beta transform.

In a joint work with Jay Mehta, we are studying *set of uniqueness* for completely additive functions. In 1969, I. Kátai proved that set of 'prime plus one' s is a set of quasi-uniqueness and conjectured that it is a set of uniqueness. This conjecture was completely settled by P.D.T.A. Elliot in 1974. On the same line, we are studying shifted Gaussian primes.

Publications:

1. Kalyan Chakraborty, Imre Katai and Bui Minh Phong, *On Real Valued Additive Functions Modulo 1*, Annales Univ. Sci. Budapest., Sect. Comp. **36**, (2012) 355–373.

2. Kalyan Chakraborty, Imre Katai and Bui Minh Phong, *On additive functions satisfying some relations*, Annales Univ. Sci. Budapest. Sect. Comp., **38**, (2012), 257-268.

3. Kalyan Chakraborty, Imre Katai and Bui Minh Phong, *On the values of arithmetic functions in short intervals*, Annales Univ. Sci. Budapest. Sect. Comp., **38**, (2012), 269-277.

4. Kalyan Chakraborty and Makoto Minamide, *On Partial sums of a spectral analogue of the Mobius Function*, Proceedings - Mathematical Sciences May 2013, Volume **123**, Issue 2, pp 193-201.

Preprints:

1. Kalyan Chakraborty and Jay Mehta, *Preventing Unknown Key Share attack using Cryptographic Bilinear Maps,* **HRI-M-12-04-003**, To appear in Journal of Discrete Mathematical Sciences and Cryptography.

2. K. Chakraborty, S. Kanemitsu and T. Kuzumaki, *Multiple zeta-function*, Preprint.

3. K. Chakraborty, S. Kanemitsu and S. Tsukada, *On Certain Applications of the Beta Transform*, Preprint.

Conference/Workshops Attended:

1. *IMSC Golden Jubilee Conference,* January 2–4, 2013, Chennai.

2. *International Conference in Number Theory,* March 25–27, 2013, China.

3. *One day Conference in Mathematics*, Hongkong University, 29th March, Hongkong.

Visits to other Institutes:

1. Eotvos Lorand University, Budapest, Hungary, September, 2012.

2. Pt. Ravishankar Shukla University, Raipur, India.

3. Institute of Mathematical Sciences, Chennai, India.

4. Pt. Ravishankar Shukla University, Raipur, India.

5. North West University, Xian, China.

6. Hongkong University, Hongkong.

Invited Lectures/Seminars:

1. *Inspire Lectures*, Modular Arithmetic, Introduction to basic cryptography, BBS College of Engn. and Pt. Ravishankar Shukla University, Allahabad, Raipur; September,December 2012.

2. *UGC Special Training*, Arithmetic on Gaussian Integers, Pt. Ravishankar Shukla University, Raipur; February 2013.

3. *International Conference in Number Theory*, Arithmetical functions with almost Gaussian integer values, Hanzhong City, China; March 2013.

4. *One day Conference in Mathematics*, Arithmetical Fourier Series and the Modular Relation, Hongkong University, Hongkong; March 2013.

Courses Taught:

1. *First Semester Algebra Course at HRI*, Harish Chandra Research Institute, Allahabad, August-December 2012.
2. *Algebra*SPIM 2012, HRI, Allahabad, June–July 2012.

Other Activities:

1. Co-ordinate NBHM MA/M.Sc and Ph.D. fellowship examinations.
2. Refereeing Papers, Post Doctoral Applications for NBHM.

Chandan Singh Dalawat

Research Summary:

We worked on an explicit and intrinsic parametrisation of the set of finite tamely ramified extensions of a local field with finite residue field, clarifying the work of Albert and Hasse. The parameter determines whether the extension is galoisian or not, and the galoisian closure in general. For galoisian extensions, it determines the smallest unramified extension of the base field which splits the given extension. We verify that two different definitions of the cohomology class of a finite galoisian extension coincide, and can be recovered from the parameter. When the given local field has odd residual characteristic, we determine all quaternionic extensions and work out a number of other instructive examples.

Publications:

1. Chandan Singh Dalawat, *Quelques " formules de masse " raffiées en degré premier*, Bulletin de la Société mathématique de France **140** (4), 599–606, cf. `arXiv:1110.6702v2`.

Conference/Workshops Attended:

1. *Workshop on the p-adic Langlands program: recent developments and applications*, Fields Institute, Toronto, 23–27 April, 2012.
2. *Workshop on the Bloch-Kato conjectures*, IISER, Poona, 17–21 July, 2012.
3. *The Pan Asian Number Theory Conference*, IISER, Poona, 23–27 July, 2012.
4. *Automorphic forms, Galois representations and L-functions*, IISER, Poona, 3–7 September, 2012.

Visits to other Institutes:

1. Fields Institute, Toronto, 17–27 April, 2012.
2. Tata Instiute of Fundamental Research, Bombay, 26–28 June, 2012.
3. Instiute of Mathematical Sciences, Madras, 3–10 October, 2012.
4. Tata Instiute of Fundamental Research, Bombay, 3–10 January, 2013.

Invited Lectures/Seminars:

1. *Higher Reciprocity*, Salahaddin University, Erbil, 28 March 2012.
2. *Local arithmetic*, Salahaddin University, Erbil, 4 April 2012.
3. *Some refined mass formulæ in prime degree*, Automorphic forms, Galois representations and L-functions, IISER, Poona, 3 September, 2012.
4. *Primitive extensions*, HRI Colloquium, 26 November 2012.
5. *Some refinements of Serre's mass formula in prime degree*, Annual meeting of the Indian Mathematical Society, Benares, 24 January 2013.

Other Activities:

Gave a course of twelve lectures on number theory at the Salahaddin University, Erbil, at the invitation of the International Mathematical Union. Resource person during three interactive sessions at the Nobel Laureates' Conclave, IIIT Allahabad.

Rukmini Dey

Research Summary:

With my students Pradip Kumar and Rahul Kumar Singh, I have been completing a project on interpolation between two curves by piecewise minimal surfaces and solitonic surfaces.
With Saikat Chatterjee and Indranil Biswas, I have completed a project of geometric prequantization of the path space of a prequantized manifold.
With Dileep Jatkar and Samir Paul, I have been working on geometric prequantization of the Hamiltonians of a finite Toda system.
Finally, I have been working on deriving some non-trivial identities from some identities of Ramanujan's using some aspects of minimal surfaces and solitons.

Publications:

1. Rukmini Dey, Varghese Mathai, *Holomorphic Quillen determinant bundle on integral compact Kähler manifolds* Quart. J. Math. 00 (2013), 1-10, (Dan Quillen memorial issue); arXiv:1202.5213v3

Preprints:

1. Rukmini Dey, Pradip Kumar, Rahul Kumar Singh, *Interpolation of two real anayltic curves by piecewise minimal surfaces and solitonic surfaces*

2. Rukmini Dey, Dileep Jatkar, Samir Paul, *Geometric prequantization of the Hamiltonians in finite Toda systems*

3. Indranil Biswas, Saikat Chatterjee and Rukmini Dey, *Geometric prequantization on the path space of a prequantized manifold*

4. Rukmini Dey, *Ramanujan's identities, minimal surfaces and solitons*

Visits to other Institutes:

1. ICTS, Bangalore, June 2012.

2. TIFR-CAM, Bangalore,June 2012

3. RRI, Bangalore, June 2012.

Invited Lectures/Seminars:

1. *Some Aspects of Minimal Surfaces* , Colloquium, TIFR-CAM, Bangalore, June, 2012.

2. *Some Aspects of Minimal surfaces*, Seminar, RRI, Banglore, June 2012.

Other Activities:

1. Currently Ph.D guide to a graduate student, Mr. Pradip Kumar.

2. Project Coordinator to a graduate student, Mr. Rahul Kumar Singh, *Osserman and Bernstein's theorem for minimal surfaces* , HRI, Jan-May 2013.

3. Instructor, Complex manifolds, HRI, August - December, 2012.

4. I am serving in Mathematics Graduate Committee, HRI colloqiuim committee and Faculty Advisory Committee.

Ratnakumar Peetta Kandy

Research Summary:

My work in the last one year, has been confined to the one with my Ph. D students, essentially on three projects. The first one is in the area of Schrödinger equations, that I have been involved, for the last few years. Jointly with Mr. Vijay Sohani, we have established a global wellposednes result for the Schrödinger equation for the twisted Laplacian on $\mathbb{C}^n$. When $n = 1$, this represents a magnetic Schrödinger equation in the plane, corresponding to a constant magnetic field. This work is just completed and extends our earlier work on local wellposedness recently appeared in Journal of Functional Analysis.

Jointly with Divyang Bhimani, we have been exploring eigen function expansion for the subLaplacian on nil manifolds associated with the Heisenberg group. We have obtained some preliminary result in this direction, for reduced Heisenberg group.

The third project involves the study of maximal functions along surfaces in $\mathbb{R}^n$, jointly with Ramesh Manna. We have obtained some L^p boundedness result, in case of surfaces given by graph of sufficiently smooth functions, whose level sets satisfy certain curvature conditions.

Publications:

1. S. Parui, Ratnakumar P.K and S. Thangavelu *Analyticity of the Schrodinger propagator on the Heisenberg group,* Monatsh **168-no.2**, 279-303, (2012)

2. Ratnakumar P.K and Vijay Kumar Sohani, *Non linear Schrodinger equation for the twisted Laplacian,* Journal of Functional Analysis, **256-no.1**, 1-27, (2013)

Preprints:

1. Ratnakumar P.K and Vijay Kumar Sohani, *Non linear Schrödinger equation for the twisted Laplacian-Global wellposedness,* (preprint in preparation)

Conference/Workshops Attended:

1. *Mathematical Panorama Lectures and Workshop - Eigenvalues of*

Operators with Gaps and Applications to the Dirac Operator, at TIFR CAM, Bangalore , India, 26th October - 9th November, 2012.

2. *School on Modular form at Kerala School of Mathematics*, India, 03-19th October, 2012.

Visits to other Institutes:

1. Kerala School of Mathematics, Calicut, India, October, 2012,
2. TIFR CAM, Bangalore, India, 26th October - 9th November, 2012.

Invited Lectures/Seminars:

1. *An uncertainty principle on the Heisenberg group*, Symposia on Lie theory, 78th Annual conference of the Indian Math. Society, Banaras Hindu University, Varanasi, January, 2013.

Academic recognition/Awards:

- Nil

Other Activities:

1. Taught the course in Analysis II, in Coursework for first year Ph.D. Students, January to April 2013.
2. Served as Convener, Pantry and Guest House committee at HRI.

Gyan Prakash

Research Summary:

Ben Green in 2003, had proved that a dense subset of primes contains infinitely many three term arithmetic progression. The results of Ben Green were improved by H. Helfgott and A. Roton, who also simplified the proof. We observed that the methods of Helfgott and Roton gives the following more general result.

We say that the k-tuple of integers $\widetilde{h}_k = (h_1, \cdots, h_k) \in \mathbf{Z}^k$ is admissible if $h_i's$ are distinct and given any prime p, there exists an integer n such that $n + h_i$ is co-prime to p for all i. Let $C_{\widetilde{h}_k}$ be the subset of integers containing those integers n for which the smallest prime factor of $n + h_i$ is at least $n^{1/5k}$ for any i. We show that for any admissible $\widetilde{h}_k$, a dense subset of $C_{\widetilde{h}_k}$ contains infinitely many three term arithmetic progression. When $k = 1$ and $\widetilde{h}_1 = (0)$, this gives us the result of Helfgott and Roton mentioned above, while when $k = 2$, and $\widetilde{h}_2 = (0, 2)$, we obtain the following result of Green and Tao. A dense subset of Chen primes contain infinitely many three term arithmetic progression. A prime p is said to be Chen prime if $p + 2$ has at most two prime factors.

Preprints:

1. Gyan Prakash, *A remark on a paper of Helfgott and Roton,* (in preparation)

Conference/Workshops Attended:

1. *Recent Trends in Ergodic Theory and Dynamical systems*, India, December 2012.

Visits to other Institutes:

1. Institute of Mathematical Sciences Chennai, India, July 2012 and October 2012.

Invited Lectures/Seminars:

1. *Roth's theorem in primes*, AIS Number Theory: The Circle Method, National Centre for Mathematics, IMSc. Chennai, June 2012.

Other Activities:

1. Gave a course to second year students in "Ergodic methods in Additive Combinatorics" during August-December 2012.

2. Member of Mathematics visitors committee, Housing allocation committee and Medical committee at HRI.

Ravindranathan Thangadurai

Research Summary:

It is known that the classical modular j-invariant Fourier coefficients odd values are supported on $n \equiv 7 \pmod 8$. However, it was unknown that whether there are infinitely many Fourier coefficients takes odd values or not. We proved that there are indeed infinitely many values of $n \equiv 7 \pmod 8$ for which those Fourier coefficients are odd.

In 2008, it was proved that an integral binary quadratic forms with non-zero discriminant represents an arithmetic progression of infinite length if and only if the discriminant is a perfect square of an integer. We proved that if $Q(x, y) = ax^2 + bxy + cy^2$ is an integral binary quadratic form with discriminant $d = b^2 - 4ac \neq 0$ where d is not a perfect square of an integer, then if Q represents an arithmetic progression, say, $kn + \ell$ for $n = 0, 1, \cdots, R - 1$, then there exist absolute constants $C > 0$ and $L > 0$ such that

$$R < C\ell(k^2|d|)^L.$$

For a given integer $n \geq 2$, let $S(n)$ be the set of all distinct prime divisors of n. Then Erdős-Wood's conjectured that there exists an integer $k \geq 2$ such that if $S(n+1) = S(m+1)$, $S(n+2) = S(m+2), \cdots$ and $S(n+k) = S(m+k)$, then $m = n$. We proved that there are $cx/\log x$ number of integers $n \leq x$ which satisfy Erdős-Wood's conjecture with $k = 2$ with $c > 2$.

We studied the relation between the unproven prime k-tuple conjecture and the other natural question of the minimal length interval having precisely ℓ primes for a given integer $\ell \geq 1$.

Recently, it was known that the Diophantine equation $x^3 + by + 1 = xyz$ has finitely many solution and the number of integer solutions is less than or equal to $6b + o(b)$ for all large enough b. If (x, y, z) is a positive integral solution of the above equation, then we obtained a bound for x, y and z in terms of b alone.

Publications:

1. B. Sury and R. Thangadurai, *S. D. Chowla and S. S. Pillai - the story of peerless Indian Mathematicians,* Resonance **17**, 855-883, (2012)

2. J. Tanti and R. Thangadurai, *Distribution of residues and primitive roots,* Proc. Indian Acad. Sci. (Math. Sci), **123**, 203-211, (2013)

Preprints:

1. Pallab Kanti Dey and R. Thangadurai, *The length of an arithmetic progression represented by a binary quadratic form,* To appear in: Amer. Math. Monthly.

2. M. Ram Murty and R. Thangadurai, *On the parity of the fourier coefficients of j-function,* (2012).

3. S. Subburam and R. Thangadurai, *On norm form Diophantine equations*, (2012).

4. S. Subburam and R. Thangadurai, *On Erdős-Wood's Conjecture*, (2013).

5. S. Subburam and R. Thangadurai, *On the Diophantine equation $x^3 + by + 1 - xyz = 0$*, (2013).

6. K. Viswanadham and R. Thangadurai, *On the prime k-tuple conjecture*, (2013).

7. K. Senthil Kumar, R. Thangadurai and M. Waldschmidt, *Liouville sets and Liouville fields*, In preparation, (2013).

Conference/Workshops Attended:

1. *Theory of Prime numbers and related areas*, Kerala School of Mathematics, India, May, 2012.

2. *Indo-French Symposium on "Automorphic Forms, Galois Representations and L-functions"*, IISER Pune, India, September, 2012.

3. *Workshop on Modular forms*, Kerala School of Mathematics, India, October, 2012.

4. *Conference in Number Theory*, Jadavpur University, India, December, 2012.

5. *Influence of Ramanujan and other Indian Mathematicians*, Central University of Tamilnadu, India, December, 2012.

6. *National Symposium on Mathematics and its applications*, Gopal Govind Poy Raiturcar College, Goa, January, 2013.

7. *Workshop on Number theory and Dynamical Systems*, Kerala School of Mathematics, India, February, 2013.

8. *National Seminar on Ramanujan - The legend of infinity*, St Mary's college, Tutucorin, India, February, 2013.

Visits to other Institutes:

1. Kerala School of Mathematics, Kozhikode, India, May, October, 2012 and February, 2013.
2. Institute of Mathematical Sciences, Chennai, India, July, 2012 and February, 2013.
3. SASTRA University, Tanjavur, India, July, 2012.
4. IISER, Pune, India, September, 2012.
5. Jadavpur University, Kolkata, India, December, 2012.
6. Central University of Tamilnadu, Thiruvarur, India, December, 2012.
7. St Mary's College, Tutucorin, India, February, 2013.

Invited Lectures/Seminars:

1. *Highly Composite Numbers*, Theory of Prime numbers and related areas, Kerala School of Mathematics, Kozhikode, May, 2012.
2. *Parity of Fourier Coefficients of j-function*, Indo-French Symposium, IISER, Pune, September, 2012.
3. *RSA Cryptosystems*, Outreach Programme for school children, Kerala School of Mathematics, Kozhikode, October, 2012.
4. *Partition functions*, Workshop on Modular forms, Kerala School of Mathematics, Kozhikode, October, 2012.
5. *Distribution of residues modulo p*, Conference in Number Theory, Jadavpur University, Kolkata, December, 2012.

Other Activities:

1. Gave a first year course on "Analysis - I" during August - December, 2012.

2. Co-guide of Mr. S. Subburam who submitted Ph. D. thesis on "Some Problems in Diophantine equations" at SASTRA University, Tanjavur, February, 2013.

3. Convener of Transport Committee and member of Local works committee at HRI.

Manoj Kumar (Yadav)

Research Summary:

Let G be a finite group minimally generated by $d(G)$ elements, and $Aut_c(G)$ denote the group of all (conjugacy) class preserving automorphisms of G. Continuing our work [Class preserving automorphisms of finite p-groups, J. London Math. Soc. **75(3)** (2007), 755-772], we studied finite p-groups G such that $|Aut_c(G)| = |\gamma_2(G)|^{d(G)}$, where $\gamma_2(G)$ denotes the commutator subgroup of G. If G is such a p-group of class 2, then we proved that $d(G)$ is even, $2d(\gamma_2(G)) \leq d(G)$ and the set of invariants of the abelian group $G/Z(G)$ is $\{p^e\}$, where $Z(G)$ denotes the center of G and p^e is the exponent of $G/Z(G)$. When the nilpotency class of G is larger than 2, we proved the following (surprizing) result: Let G be a finite p-group of nilpotency class at least 3 and $|Aut_c(G)| = |\gamma_2(G)|^{d(G)}$. Then $d(G) = 2$. Moreover, if either p is odd, or $p = 2$ and $|\gamma_2(G)/\gamma_3(G)| > 2$, then $|Aut_c(G)| = |\gamma_2(G)|^{d(G)}$ if and only if $d(G) = 2$ and $\gamma_2(G)$ is cyclic. Here $\gamma_3(G)$ denotes the third term in the lower central series of G. As an application, we classified finite nilpotent groups G such that $|G/Z(G)| = |\gamma_2(G)|^{d(G)}$. For proving the above results, we introduced a notion of Camina-type groups, which is a generalization of Camina groups, and obtained some interesting results similar to Camina groups. We used Lie theoretic techniques and heavy commutator calculations as tools.

Jointly with Dr. Rajat K. Nath, we studied the probability of a given element, in the commutator subgroup of a group, to be equal to a commutator of two randomly chosen group elements. We computed explicit formulas for calculating this probability for some interesting classes of groups having only two different conjugacy class sizes, including Camina groups of prime power order and freest prime power order groups (i.e., groups admitting a generating set in which no two different elements commute) of nilpotency class 2. We re-proved the fact that if G is a finite group such that the set of its conjugacy class sizes is $\{1, p\}$, where p is a prime integer, then G is isoclinic (in the sense of P. Hall) to an extraspecial p-group.

Preprints:

1. Manoj K. Yadav, *Class preserving automorphisms of finite p-groups II*.
2. Rajat K. Nath and Manoj K. Yadav, *Probability that a given element of a group is a commutator of any two randomly chosen group elements,* (in

preparation).

Conference/Workshops Attended:

1. *16th Midrasha Mathematicae on Words and Growth*, Israel, June 2012.
2. *National conference in advances in Mathematical Sciences*, India, October 2012.
3. *INSA Young Scientists Conclave 2012*, India, November 2012.

Visits to other Institutes:

1. Hebrew University of Jerusalem, Jerusalem, Israel, June 2012.
2. Tezpur University, Tezpur, Assam, India, October 2012.
3. Mathematical Sciences Institute, The Australian National University, Canberra, Australia, January - March 2013.

Invited Lectures/Seminars:

1. *Capable groups*, National conference in advances in Mathematical Sciences, MNNIT, Allahabad, October 2012.
2. *Basic group theory lecture*, general lecture, Dept. of mathematics, Tezpur University, Tezpur, October 2012.
3. *Automorphisms, commutator subgroup and central quotient*, general lecture, Dept. of mathematics, Tezpur University, Tezpur, October 2012.

Academic recognition/Awards:

- Indo-Australia Early Career Visiting Fellowship 2012 - 2013 (for eight months), 2012.

Other Activities:

1. Refering work: I refereed papers for the following journals: Arch. der Math., Comm. Algebra, Indian J. Pure and Applied Mathematics, Proc. Indian Acad. Sciences (Math. Sci.), J. Algebra and its Applications, 2012 - 2013.

2. I was a member of various committees constituted in HRI, 2012 - 2013.

Satya Deo

Research Summary:

During this year I have mainly worked on my DST project "Topological Methods in Combinatorial Mathematics". I have been trying to understand the major works done by Lazlo Lovas, Brian Birch, Tverberg and others who have made fundamental use of algebraic topology, specially the homotopy theory and the Borsuk-Ulam theorem to prove the Kneser conjecture and the Birch's conjecture of combinatorics. Then, I was able to make some contributions of my own using the index theory. I have proved an important result that the index of a finitistic G-space X, where G is a compact Lie group acting on the space X without fixed points, is finite. This result is useful in proving theorems of the type stated above for more general spaces than polyhedra. In fact, we have obtained an interesting generalization of the Central Point Theorem and the Tverberg Theorem for Hausdorff spaces using our index result.

We have also obtained some results on the nonembeddings of Combinatorial 8-Manifolds having cohomology of the quaternionic projective plane analogous to the facts that the real projective plane cannot be embedded in 3-dimensional Euclidean space and that the complex projective plane cannot be embedded in the 6-dimensional Euclidean space. In proving this result we have used the existence of the three 8-manifolds on 15 vertices, called BK manifolds, and the Z_2-index theory for equivariant maps.

Publications:

1. Satya Deo, *Index of a finitistic space and a generalization of the Topological Central Point Theorem*, Journal of the Ramanujan Mathematical Society **28**, 223-232 (2013)

Preprints:

1. Satya Deo, *Combinatorial 8-manifolds Having Cohomology of Quaternionic Projective Plane and Their Nonembeddings*.

Conference/Workshops Attended:

1. National Science Academies' Lecture Workshop on "Non Euclidean Geometry to Rubber-sheet Geometry", NASI, Allahabad, June 2012.
2. Conference on "Recent Developments in Mathematics", MNNIT, Allahabad, Oct 2012.
3. Annual conference of the Indian Mathematical Society, BHU, Varanasi, Jan 2013
4. Conference on "The Legacy of Ramanujan", University of Delhi, Delhi, Dec 2012
5. Conference on "Radiation Biology and Cancer", Nehru Gram Bharati University, Allahabad, Dec 2012

Visits to other Institutes:

1. IIT, Kanpur, June 2012
2. Bhawan's Mehta Science College, Bharawari, July 2012.
3. College of Homeopathy, Etawa, July 2012.
4. R.D.University, Jabalpur

Invited Lectures/Seminars:

1. *Algebraic Equations*, Workshop of Utsahi Physics Teachers, IIT, Kanpur, June 2012
2. *Rubber-sheet Geometry and Topology*, INSPIRE Lecture, College of Homeopathy at Etawa, U.P., July 2012
3. *Algebric Topology and Combinatorics*, Annual Session of the National Academy of Sciences, India, BHU, Varanasi, November 2012.
4. *Geometric Constructions- Abel and Galois*, DRS Lecture at Jabalpur University, Jabalpur, Oct 2012

Academic recognition/Awards:

- Senior Scientist Platinum Jubilee Fellowship of the National Academy of Sciences, India, Dec 2012,
- Member, Programm Advisory Committee in Mathematical Sciences, DST, Govt of India, July 2012
- Editor, Journal of the Indian Mathematical Society, Jan 2013.
- Elected, President of the Physical Science Section of the NASI for the year 2012.

Other Activities:

1. Organized the Annual Session of the Indian Mathematical Society at BHU, Varanasi, Jan 2013.
2. Gave the Presidential Talk of the Physical Science Section of the National Academy od Sciences, India at BHU, Varanasi during Nov 2012.

Divyang Bhimani

Research Summary:

Let $\mathbb{H}_n$ be the $(2n+1)-$ dimensional Heisenberg group, which is $\mathbb{C}^n \times \mathbb{R}$ endowed with the group law $(z,t)(w,s) := (z+w, t+s+\frac{1}{2}Im(z \cdot \bar{w}))$. The Heisenberg laplacian is given by $\pounds = -\sum_{j=1}^{n}(X_j^2 + Y_j^2)$; where $X_j = \frac{\partial}{\partial x_j} - \frac{1}{2}y_j\frac{\partial}{\partial t}$,$Y_j = \frac{\partial}{\partial y_j} + \frac{1}{2}x_j\frac{\partial}{\partial t}, j = 1,2,...,n$; are vector fields, which generate the Heisenberg Lie algebra. We have the Strichartz expanation, $f(z,s) = \sum_{k=0}^{\infty}\int_{\mathbb{R}} f * e_k^{\lambda}(z,s)(2\pi)^{n-1}|\lambda|^n d\lambda$, for $f \in L^2(\mathbb{H}_n)$ and $e_k^{\lambda}(z,s)$ are joint eigenfunctions of $\pounds$ and operator $T = i\frac{\partial}{\partial t}$; where $e_k^{\lambda}(z,s) := e^{i\lambda s}\phi_k(\sqrt{|\lambda|}z)$, $\phi_k(z) := (2\pi)^{\frac{n}{2}}\sum_{|\alpha|=k}\Phi_{\alpha,\alpha}(z)$ for each $\alpha, \beta \in \mathbb{N}^n$ and $\Phi_{\alpha,\beta}(z)$ are the special Hermite functions $\mathbb{C}^n$.
I have been studying analogous questions for nilmanifols associated to the Heisenberg group. In the case of reduced Heisenberg group $\mathbb{H}_n^{red} = \Gamma\backslash\mathbb{H}_n$, where, $\Gamma = \{(0, 2k\pi) : k \in \mathbb{Z}\}$, we have obtained that, $f(z,s) = \sum_{\lambda\in\mathbb{Z}}\sum_{k=0}^{\infty} f * e_k^{\lambda}(z,s)$, for $f \in L^2(\mathbb{H}_n^{red})$.

Invited Lectures/Seminars:

1. *Measure Theory* , Summer Programme in Mathematics (SPIM 2012), Harish Chandra Research Institute, Allahabad, 2012.

Kasi Viswanadham G

Research Summary

Let K be an algebraic number field and $\mathcal{O}_K$ be its ring of integers. Let $\zeta_K(s) := \sum_A (NA)^{-s}$ where the sum is running over all the integral ideals of K and NA denotes the "Norm" of the ideal A. It is said to be The Dedekind zeta function Associated to K. One of the main problem regarding this function is to find the growth rate on the critical line, i.e. $Re(s) = \frac{1}{2}$. In 1988, Heath-Brown showed that $\zeta_K(\frac{1}{2} + it) \ll t^{n/6+\epsilon}$. Currently, I am working on this problem to improve the upper bound given by Heath-Brown.

Publications:

1. Jaban Meher,Karam Deo Shankhadar and G K Viswanadham, *A short note on sign changes,* Accepted for publication in Proc.Indian Acad. Sci.(Math. Sci.)

Preprints:

1. R. Thangadurai and G K Viswanadham, *On Prime κ-tuple Conjecture,* (Submitted for publication)

Conference/Workshops Attended:

1. *AIS on Circle Method*, IMSc, Chennai, June 2012.
2. *School On Modular Forms*, Kerala school of mathematics ,Kerala, October 2012.

Invited Lectures/Seminars:

1. *Introduction to Selberg Sieve*, AIS on Circle Method, IMSc, Chennai, June 2012.
2. *Fourier Analysis on Finite Groups*, Summer Programme, IMSc, Chennai, July 2012.

Senthil Kumar K

Research Summary:

1. Lioville Numbers(joint work with R. Thangadurai and M. Waldschmidt). In 1962, Erdős proved that any real number (resp. any non-zero real number) can be written as a sum (resp. product) of Liouville numbers. More precisely, he proved that the maps $(x, y) \mapsto x + y$ (resp. to xy) : $\mathbf{L} \times \mathbf{L} \to \mathbf{R}$ (resp. to $\mathbf{R} \setminus \{0\}$) are surjective. Here $\mathbf{L}$ denotes the set of all Liouville numbers. A natural question arises: Is the similar results hold for polynomials in more variables?. In this work, we have studied the image of Liouville numbers under rational functions in many variables over $\mathbf{Q}$, and we proved that there are subsets S of $\mathbf{L}$ such that $\mathbf{Q} \cup S$ forms a field.

2. Mahler Classifications. In 1932, Mahler using the construction similar to Liouville numbers, classified the set of complex numbers into four classes namely: A-numbers, $S-$numbers, $T-$numbers, and $U-$numbers. In this work, we have studied the image of $U-$numbers under the rational functions over number fields. We also studied the height and degree of image of algebraic numbers under polynomials over $\mathbf{Q}$.

Preprints:

1. K. Senthil Kumar, R. Thangadurai and M. Waldschmidt, *On Liouville numbers* (in preparation).
2. K. Senthil Kumar, *Arithmetic Properties of $U-$numbers* (in preparation).

Conference/Workshops Attended:

1. *Theory of Prime Numbers and Related Areas*, India, May, 2012.
2. *AIS school on Number Theory:Circle Method*, India, June, 2012.
3. *CMI- IMSc Lecture Series in Number Theory*, India, October, 2012.

Visits to other Institutes:

1. Institute of Mathematical Sciences, India, October-December 2012.

Other Activities:

1. Gave a mini Course on Local-Global principal for quadratic forms over $\mathbf{Q}$, AIS school on Number Theory, IMSC, Chennai, June, 2012.

Eshita Mazumdar

Research Summary:

My research area is Number theory and combinatorics.In this year I mainly focused on additive combinatorics specifically on zero-sum problem. Along with that I read several research papers related to that.In the Number theory portion I tried to get a complete overview of algebraic Number theory.I studied many of the topics like additive number theory,graph theory,elementrary number theory,combinatorics,algebraic number theory,analytic number theory etc.

Conference/Workshops Attended:

1. *Celebrating the 125th birth Anniverssary of Srinivasa Ramanujan, Conference in Number Theory* ,Jadavpur University,Kolkata, India, December 12-14, 2012

2. *The Legecy of Srinivasa Ramanujan,International Conference*,University of Delhi,India, December 17-22,2012.

3. *Workshop on ISL Combinatorics*,Harish Chandra Research Institute, Allahabad,India,June 1-14,2012.

Talk

1. *Generalization of Schur's theorem*, Workshop on ISL Combinatorics, Harish Chandra Research institute, Allahabad, June,2012.

Ramesh Manna

Research Summary:

I am studying the maximal operators along hypersurfaces given by the graph of functions whose level sets satisfying some geometric properties. 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

$$A_c f(x) = \frac{1}{|\Sigma_c|} \int_{\Sigma_c} f(x-y)\, d\mu(y) \tag{1}$$

where μ denotes the surface measure on Σ_c induced by the Lebesgue measure and $|\Sigma_c| = \mu(\Sigma_c)$. Define the corresponding maximal operator by

$$Mf(x) = \sup_{c>0} |A_c f(x)|. \tag{2}$$

Boundedness of this maximal operator on $L^p(\mathbb{R}^n)$ is being studied.

Pradip Kumar

Research Summary:

Symplectic structures on Fréchet manifolds:

1. **Almost complex structure on Path space**:
   Let M be a complex manifold and let $PM := C^\infty([0,1], M)$ be space of smooth paths over M. I prove that the induced almost complex structure on PM is weak integrable by extending a result of Indranil Biswas and Saikat Chatterje. Further I prove that if M is smooth manifold with corner and N is any complex manifold then induced almost complex structure $\mathfrak{J}$ on Fréchet manifold $C^\infty(M, N)$ is weak integrable.

2. **Symplectic structures on loop space**:
   In this article I discussed two class of symplectic structure on loop space LM and based loop space L_pM. It is known that loop space admits quasi symplectic form σ^g for given Riemannian metric g. Also for any symplectic manifold (M, α), corresponding loop space admits weak symplectic form Ω^α. Hence we have two class of symplectic structure on $LM(L_pM)$, σ^g and Ω^α. I showed that if there is an isotopy ϕ such that $\phi^*(\alpha_s) = \alpha_0$, then there exists an isotopy on loop space $\widetilde{\phi}$ such that $\widetilde{\phi}^*(\Omega^{\alpha_s}) = \Omega^{\alpha_0}$. This proves that Loop space admits 'Darboux chart' for any Ω^α. Since in L_0M both σ^g and Ω^α are weak symplectic, I showed that there does not exists any isotopy which takes σ^g to Ω^α. Next I showed that if (LM, σ) admits 'Darboux chart' and let (L_pM, σ') be symplectic submanifold, then (L_pM, σ') admits 'Darboux chart', For finite dimension it is a trivial result, but this result may not true even for Banach symplectic submanifold.

3. **PLB manifold with compatible symplectic structure**:
   Suppose M be a Fréchet manifold with weak symplectic structure σ such that M is projective limit of weak symplectic Banach manifolds $\{(M_i, \phi_{ij})\}_{i,j\in\mathbb{N}}$, $M_i's$ are modeled over reflexive Banach space and σ is compatible with inverse system. I associated each point $x \in M$, a Fréchet space H_x. I proved that if H_x are locally constant, then with certain smoothness condition, Darboux theorem holds.

Publications:

1. Almost complex structure on path space. International Journal of Ge- ometric Methods in Modern Physics Vol. 10, No. 3 (2013) 1220034 (7 pages)

Preprints:

1. Symplectic structures on loop spaces.
2. Darboux chart on projective limit of weak symplectic Banach manifold.

Visits to other Institutes:

1. 6 June to 16 June 2012 ICTS Banglore, India.

Jay Gopalbhai Mehta

Research Summary:

An independent work includes study of completely additive complex valued functions over a principal configuration (which is union of finitely many lattices in complex plane with origin in common). We showed that a completely additive functions over principal configuration having constant values in some discs of complex plane is (identically) the zero function.

In a joint work with Prof. Kalyan Chakraborty, we are studying *set of uniqueness* for completely additive functions. In 1969, I. Kátai proved that set of 'prime plus one' s is a set of quasi-uniqueness and conjectured that it is a set of uniqueness. This conjecture was completely settled by P.D.T.A. Elliot in 1974. On the same line, we are studying shifted Gaussian primes.

Preprints:

1. Kalyan Chakraborty and Jay Mehta, *Preventing Unknown Key Share attack using Cryptographic Bilinear Maps*, HRI-M-12-04-003, accepted in Journal of Discrete Mathematical Sciences and Cryptography.

2. Jay Mehta, *On arithmetical functions having constant values in some domain*, accepted for publication in Acta. Math. Hungarica.

Invited Lectures/Seminars:

1. *Topology*, Summer Program in Mathematics (SPIM 2012), Harish Chandra Research Institute, Allahabad, June 2012.

2. *Tutorials in Number Theory*, Summer Program in Mathematics (SPIM 2012), Harish Chandra Research Institute, Allahabad, June 2012.

3. *Arithmetical functions over Gaussian integers*, Students Seminar, Harish Chandra Research Institute, Allahabad, August 2012.

Other Activities:

1. Compiled HRI Annual Report for the academic year 2011-2012, May-July 2012.

Akhilesh P

Research Summary:

The current aim of my thesis work is obtain an optimal answer to the following question. When the sequence of squares of the natural numbers is coloured with K colours, $K \geq 1$ an integer, let $s(K)$ be the smallest integer such that each sufficiently large integer can be written as the sum of no more than $s(K)$ squares, all of the same colour. Then the problem is to determine optimal upper bounds for $s(K)$, for large K. This problem is analogue of a similar problem for the sequence of prime numbers, which was recently settled by D.S. Ramana and O. Ramaré. I am studying the possibility of extending their method to my question, the key obstruction being the fact that the squares are much more sparse than the primes.

In addition to the above, I made numerical studies on the question of determining how close the integer points on affine circles can be. More precisely, on $X^2+Y^2 = R^2$, the circle of radius R, with $R^2 = N$ an integer, let us take $x_1, x_2, ..., x_n$, points with integer co-ordinates, and set $d_{ij} = \|x_i - x_j\|_2$ for any i, j. Let us set

$$\Delta(x_1, x_2, ..., x_n) = \frac{log(\prod_{1 \leq i < j \leq n} d_{ij})}{log(N)} .$$

Then the problem is to study how the infimum $\Delta(R, n)$ of this quantity, taken over all sets of n integer points on $X^2 + Y^2 = R^2$, grows with R and n. This problem turns out to be interest in many questions in number theory. Using C programming and computer cluster facility at the Institute we have computed large number of values of $\Delta(x_1, x_2, ..., x_n)$ with the intention of formulating conjectures on the precise growth $\Delta(R, n)$.

The Beurling-Selberg function is a special function of importance in numerous applications of Fourier analysis to number theory. In joint work with D.S. Ramana , we revisit this function as a solution of a difference equation. We then show that this point of view leads to natural and simple proofs of the properties of this function. This is the content of the first publication listed below.

Publication:

1. P. Akhilesh and D S Ramana , "A remark on the Beurling–Selberg function" in Acta Mathematica Hungarica .

Conference/Workshops Attended:

1. *The international conference The Legacy of Srinivas Ramanujan* , University of Delhi, December 17 -22, 2012.
2. *AIS Number Theory : The circle method* ,Institute of Mathematical Sciences, Chennai, 25 Jun - 14 Jul 2012.
3. *School on Modular Forms*,KSOM, Kozhikode,3 October - 19 October 2012
4. *Workshop on Number Theory and Dynamical Systems* ,KSOM, Kozhikode,04-08 February, 2013

Other Activities:

1. Visited KSOM in the period of 1 to 20 April 2013
2. Delivered a talk about Large Sieve in 19 th April 2013 ,KSOM Kozhikode

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 it. These automorphisms form a group which we denote by $Aut_c(G)$. Let $Inn(G)$ denote the group of inner automorphisms of G. We study the the quotient group $Aut_c(G)/Inn(G)$ and prove that If $\gamma_k(G)$ the k'th term in the lower central series of G for some $k \geq 1$ is cyclic, then $Aut_c(G)/Inn(G)$ is nilpotent of class at most k. In the way to proving this result we also prove that If G is a solvable group of length l, then $Aut_c(G)$ is a solvable group of length either l or $l-1$, which extends a result of C.H. Sah.

An automorphism of G is called an IA-automorphism if it induces the identity mapping on $G/\gamma_2(G)$, where $\gamma_2(G)$ is the commutator subgroup of G. Let $IA_z(G)$ be the group of those IA-automorphisms, which fix the center element-wise and let $Autcent(G)$ be the group of central automorphisms, the automorphisms that induce the identity mapping on the central quotient. Extending a result of Manoj Yadav we prove that $IA_z(G)$ and $IA_z(H)$ are isomorphic for any two finite isoclinic groups G and H. Also, for a finite p-group G, we give a necessary and sufficient condition to ensure that $IA_z(G) = Autcent(G)$.

Preprints:

1. Vivek Kumar Jain, Pradeep Kumar Rai and Manoj K. Yadav, *On finite p-groups with abelian automorphism group,* Accepted for publication in Internat. J. Algebra Comput.

2. Pradeep Kumar Rai, *On IA-Automorphisms that fix the center element-wise,* Accepted for publication in Proc. Indian Acad. Sci., Math. Sci.

3. Pradeep Kumar Rai, *On class-preserving automorphisms,* Submitted for publication.

Invited Lectures/Seminars:

1. *Finite p-groups with abelian automorphism group*, Student seminar talk, Harish Chandra Research Institute, Allahabad, August, 2012.

Karam Deo Shankhadhar

Research Summary:

1. Sign changes

(i) (joint work with J. Meher and G. K. Viswanadham): In this research work, we present a quantitative result for the number of sign changes for the sequences $\{a(n^j)\}_{n\geq 1}, j = 2, 3, 4$ of the Fourier coefficients of normalized Hecke eigen cusp forms for the full modular group $SL_2(\mathbb{Z})$. We also prove a similar kind of quantitative result for the number of sign changes of the q-exponents $c(p)$ (p vary over primes) of certain generalized modular functions for the congruence subgroup $\Gamma_0(N)$, where N is square-free.

(ii) (joint work with J. Meher and S. Pujahari): In this work, we give criterions for infinitely many sign changes of the coefficients of any general Dirichlet series if the coefficients are real numbers. We also provide examples where our criterions are applicable.

2. Higher degree Jacobi cusp forms (joint work with M. Manickam): Work is in progress to establish Eichler-Zagier correspondence between the space of Jacobi cusp forms of matrix index $J^{\text{cusp}}_{k+\frac{g+1}{2},M}(N,\chi)$ and the space of cusp forms of half-integral weight $S_{k+\frac{1}{2}}(2\det(2M)N,\chi)$. We have partial result in this direction. If we could establish Eichler-Zagier correspondence properly, it will give us a path to study Hecke theory on the space of Jacobi cusp forms of higher degree by using the known theory for half-integral weight cusp forms. Using these results, one can relate the Fourier coefficients of higher degree Jacobi cusp forms with the special values of certain L-functions similar to the degree 1 case.

Publications:

1. B. Ramakrishnan and Karam Deo Shankhadhar, *On a correspondence between Jacobi cusp forms and elliptic cusp forms*, International Journal of Number Theory, **9** (2013), 917-937.

2. Jaban Meher, Karam Deo Shankhadhar and G. K. Viswanadham, *A short note on sign changes*, Proc. Ind. Acad. of Sciences, To appear.

Preprints:

1. B. Ramakrishnan and Karam Deo Shankhadhar, *Non-vanishing of L-functions associated to cusp forms of half-integral weight*, Revised version

submitted for publication in Oman Conference proceeding (Springer).

2. Jaban Meher, S. Pujahari and Karam Deo Shankhadhar, *Sign changes of coefficients of certain Dirichlet series* (in preperation).

Conferences/Workshops Attended:

1. *The Legacy of Srinivasa Ramanujan - An International Conference*, 17-22 December 2012, University of Delhi, Delhi, India.

2. *School on Modular forms*, 3-19 October 2012, Kerala School of Mathematics, Kozhikode, India.

Visits to other Institutes:

1. Kerala School of Mathematics, Kozhikode, India, 7th February-3rd March 2013.

Invited Lectures/Seminars:

1. A contributed talk on *Non-vanishing of L-functions associated to cusp forms of half-integral weight*, The Legacy of Srinivasa Ramanujan - An International Conference , University of Delhi, Delhi, December 17-22, 2012.

Other Activities:

1. Took tutorial classes for the school on Modular Forms, Kerla School of Mathematics, Kozhikode, October 2012.

2. Took tutorial classes in Field Theory for the ATM programme AFS-III, Harish-Chandra Research Institute, Allahabad, July 2012.

3. Helped in organizing HRI Science Talent Test, 2012 (Mathematics).

Sneh Bala Sinha

Research Summary:

My research area is Number theory and combinatorics.I have read some algebraic number theory, some additive combinatorics,some elementrary number theory and some papers on zero-sum.

Conference/Workshops Attended:

1. *Celebrating the 125th birth Anniverssary of Srinivasa Ramanujan, Conference in Number Theory* ,Jadavpur University,Kolkata, India, December 12-14, 2012

2. *The Legecy of Srinivasa Ramanujan,International Conference*,University of Delhi,India, December 17-22,2012.

3. *Workshop on ISL Combinatorics*,Harish Chandra Research Institute, Allahabad,India,June 1-14,2012.

Tutorial

1. I took a tutorial in the program SPIM on the topic Algebra during 16th to 4th July,2012.

Talk

1. *Talk on Schur's Theorem*, Workshop on ISL Combinatorics, Harish Chandra Research institute, Allahabad, June,2012.

Vijay Kumar Sohani

Research Summary:

The local well posedness of the nonlinear Schrödinger equation for the twisted Laplacian has been studied in our paper (J. Funct. Anal. 265 (1) (2013) 1-27) for initial value in $\tilde{W}^{1,2}(\mathbb{C}^n)$. However this approach does not conclude energy conservation and the finite time blow up exists or not. We overcome this difficulty by introducing the Sobolev space $\tilde{W}^{1,2}_{\mathcal{L}}(\mathbb{C}^n)$ defined using the operators Z_j and $\overline{Z}_j$, which is the natural one in this context. Though they do not commute with Schrödinger propagator $e^{-it\mathcal{L}}$, they have a reasonable commutation relation, suitable for us. The advantage of working with this Sobolev space is that we get energy conservation in this case. From this we can show that there is no finite time blow up, hence can conclude global existence in the Sobolev space $\tilde{W}^{1,2}_{\mathcal{L}}(\mathbb{C}^n)$.
Now we consider the critical case $\alpha = \frac{2}{n-1}$. In subcritical case $0 \leq \alpha < \frac{2}{n-1}$ for each α, we have some $q > 2$ such that $(q, 2+\alpha)$ be an admissible pair, which is not the case when $\alpha = \frac{2}{n-1}$. To treat critical case, we adopt truncation argument method of Cazenave and Weissler (Lect. Notes Math. 1394, Springer 1989). To prove local existence, we truncate the given nonlinearity G and obtain solution for the truncated problem. Now we obtain solution u for given nonlinearity G by using Strichartz estimates and by passing to the limit.

Publications:

1. V. K. Sohani and P. K. Ratnakumar, *Nonlinear Schrödinger equation for the twisted Laplacian,* to appear in J. Funct. Anal. **265 (1)**, 1-27, (2013).

2. V. K. Sohani, *Strichartz Estimates for the Schrödinger propagator for the Laguerre Operator,* to appear in Proc. Math. Sci.

Preprints:

1. P. K. Ratnakumar, V. K. Sohani, Nonlinear Schrödinger equation for the twisted Laplacian- global well posedness, (in preparation).

2. V. K. Sohani, Nonlinear Schrödinger equation for the twisted Laplacian in the critical case, (in preparation).

Conference/Workshops Attended:

1. *MPLW Eigenvalues of Operators with Gaps and Applications to the Dirac Operator*, TIFR-CAM, Bangalore, India, 26th October to 9th November, 2012.

Other Activities:

1. I took two tutorial on Complex Analysis in Summer Programme in Mathematics (SPIM), HRI, Allahabad, June-July 2012.

2. Tutor for Complex Analysis in AFS-III, HRI Allahabad, 6-31 July, 2012.

Surjeet Kour

Research Summary:

My current area of research is "Commutative Algebra". More precisely I am working on simple derivations, locally nilpotent derivations and locally nilpotent higher derivations. In recent years many peoples have worked in the area of locally nilpotent higher derivations and they have observed that many results which were true for locally nilpotent derivations in characteristic zero can be generalized to locally nilpotent higher derivations in arbitrary characteristic.

Let us consider the following general question. Let n be a positive integer and R be an domain. We say that R has the property $FG(n)$ if for every locally nilpotent R-derivation(locally nilpotent higher R-derivation) D of $A = R[x_1 \cdots, x_n]$, ker(D) is finitely generated as an R-algebra. We will write $R \in FG(n)$ to indicate that R has property $FG(n)$.

It is interesting and natural to think about the classification of rings having property $FG(n)$, for each n. It is clear that all domains of characteristic zero have the property $FG(1)$. On the other hand, it is known that if k is a field of characteristic zero and $n \geq 5$, then there exists a locally nilpotent derivation(so locally nilpotent higher derivation) of $k[x_1 \cdots, x_n]$, whose kernel is not finitely generated over k. So this question is unsolved only for $n = 2, 3, 4$.

This question for $n = 2$ has been investigated by S. M. Bhatwadekar and A. K. Dutta in the article "Kernel of locally nilpotent R-derivations of $R[X, Y]$" and for $n = 3$ by S. M. Bhatwadekar and D. Daigle recntly in 2009 in the article "On finite generation of kernels of locally nilpotent R-derivations of R[X,Y,Z]". This article gives significant answer to normal integral domain with some condition.

The question whether fields of characteristic zero have property $FG(4)$ is still open.

Second interesting question is whether this property is a local property or not. That is if for every multiplicative close subset $S \subset R$, $S^{-1}A$ has FG(n), does A has FG(n) and vice-versa. This results about locally nilpotent derivations in characteristic zero have been discussed by S.M. Bhatwadekar and D. Daigle. I am trying to generalized these results to locally nilpotent higher derivations in arbitrary characteristic.

More precisely consider the following problem. Let R be an integral do-

main and D br a locally nilpotent higher R-derivation of $R[x_1 \cdots, X_3]$. Is kernel of D finitely generated. Ofcourse kernel of D can not be finitely generated for any domain R. So under what condition kernel of D is finitely generated.

Preprints:

1. *On kernel of loclly nilpotent higher derivations*.

Invited Lectures/Seminars:

1. *On kernel of loclly nilpotent higher derivations*, IIT Kanpur, Kanpur, January 2013.
2. *A class of simple derivations of* $k[x, y]$, , IIT Jodhpur, Jodhpur, April 2013.
3. *Invited in AFS-2 , 2013*, IIT Kanpur .

Ashwin Subodh Pande

Research Summary:

I completed and submitted a paper titled 'Topological T-duality, Automorphisms and Classifying spaces' in January 2013. The referee report was received in January 2013 and the referee's comments are being acted upon. The paper will be resubmitted for publication shortly.

In the year April 2012 to May 2013, I completed a research project on applications of the theory of Topological Stacks to some problems in the field of Topological T-duality. This work is nearly complete and has been written up as a preprint: 'Topological T-duality and a Gysin Sequence'.

In my Physics dissertation I did some work on active membranes together with Prof. R. Pandit (IISc, Bangalore) and Prof. S. Ramaswamy (TIFR-Hyderabad). The work is in the paper 'Spatiotemporal Chaos in a model for Active Membranes'. Due to some new experimental evidence, this work is being revised for publication now.

Preprints:

1. Ashwin S. Pande, *Topological T-duality, Automorphisms and Classifying Spaces,* (under refereeing)

2. Ashwin S. Pande, *Topological T-duality and a Gysin Sequence*, (in preparation)

3. A. Pande, R. Pandit and S. Ramaswamy *Spatiotemporal Chaos in a model for active membranes*, (in preparation)

Invited Lectures/Seminars:

1. *Topological T-duality, Automorphisms and Classifying Spaces*, Center for Excellence in Basic Sciences, Mumbai, January 2013.

2. *Topological T-duality, Automorphisms and Classifying Spacse*, TIFR-Center for Applicable Mathematics, Bangalore, January 2013.

Academic Report - Physics

Jayanta Kumar Bhattacharjee

Research Summary:

During the last year my efforts have centered around a couple of issues in statistical physics and nonlinear oscillators.

In statistical physics the interest has been in a gas of fermions with population imbalance exemplified by spin $-\frac{1}{2}$ fermions in an external magnetic field which allows for a difference between the number of "spin up" and "spin down" particles in thermal equilibrium. This difference can give rise to magnetism and the pairing of "up spin" and "down spin" fermions can give rise to superconductivity and one has a situation with antagonistic order parameters. The possibility of a tricritical point in such a situation with the formation of a metastable state has been known for fifty years. However the actual observation of a metastable state in the tricritical phase diagram was possible only about five years ago by looking at cold atomic gases. This resulted in a minor puzzle since the dependence of the width of the metastable region was in contradiction with what is expected on the basis of a standard Ginzburg Landau (GL) model for the tricritical point. We showed that a variation in the starting point with the free energy written with two antagonistic coupled order parameters gives a result in agreement with the observed variation of the width. The issue of a tricritical point was followed up by looking at a GL model which has been found a few years ago by starting from the microscopic Hamiltonian of a spin $-\frac{1}{2}$ fermion in an external magnetic field. We noticed that the resultant GL model which has among other things exotic superconducting phases must have a Lifshitz tricritical point in the FFLO phase . This observation allowed us to calculate the specific heat which shows a significant magnetic field dependent anomaly and compare it with the experimental evidence that has been accumulating over the last several years.

In the area of nonlinear oscillators, we have found some exact results for a class of systems governed by a variation on the Riccati equation. We have also investigated the possibility of chaotic behavior at low energies for a double pendulum. At really low energies it is a quasi- periodic motion governed by a superposition of the two normal modes. The tendency of the out of phase mode to soften with increasing amplitude prompted us to look for chaotic behavior at low energies. The system allows us to study the transition from two frequency quasi periodicity to chaos which we found is strongly dependent on initial conditions.

Publications:

1. A Sarkar, P Guha, A Ghose-Choudhury, J K Bhattacharjee, A K Mallik and P G L Leach, *On the properties of a variant of the Riccati system of equations,* J Phys A45 , 415101 (2012)

2. J Roy, A K Mallik and J K Bhattacharjee, *Role of initial conditions on the dynamics of a double pendulum at low energies*, Nonlinear Dynamics DOI 10.1007/s11071-013-0848-1, (2013)

3. A Dutta and J K Bhattacharjee, *Competing order parametrs and a tricritical point with a difference*, Physica B407 ,3722 (2012)

4. A Dutta and J K Bhattacharjee, *Lifshitz tricritical point and its relation to the FFLO superconducting state*, Phys Lett A377 , 1402 (2013)

5. D Banerjee and J K Bhattacharjee, *Study of some model quantum systems in two dimensions*, Euro J Phys 34 , 435 (2013)

Visits to other Institutes:

1. Physikalische Institut III , University of Goettingen, Germany , October 2012

Invited Lectures/Seminars:

1. *Oscillators*, Old and new, Bose Colloquium, S N Bose National Centre, Kolkata, April 2012.

2. *Extremum Principles*, Valedictory lecture for the physics Olympiad training camp, Homi Bhabha Centre for Science Education, Mumbai, May 2012.

3. it Pattern Formation in Nature, Inaugural lecture for NASI summer program ,National Academy of Sciences, Allahabad, June 2012.

4. *Nonlinear Oscillators*, Old and New Perspectives , Senfest at IPR, Institute of Plasma Research, Ahmedabad , November 2012.

5. *Centres and Limit Cycles*, A course of 4 lectures at the SERC school on nonlinear dynamics, S N Bose National Centre, Kolkata December 2012.

6. *Pattern formation in Nature*, IIIT Science Conclave, Allahabad, December 2012.

7. *Quest for a small exponent*, Conference on Complexity and Statistical Physics, Saha Institute of Nuclear Physics, Kolkata , January 2013.

8. *Oscillators and the Renormalization Group*, IIT Kharagpur Colloquium, Kharagpur, January 2013.

9. *Oscillators*, Old and new, Special NIUS lecture, Homi Bhabha Centre for Science Education, Mumbai, March 2013.

Other Activities:

1. Course at HRI integrated PhD program "Statistical Physics " Jan - April (2013)

Sandhya Choubey

Research Summary:

My research spans mainly the area of neutrino physics. Neutrino physics has seen some of the most spectacular results in the last decade, which have opened a window to the physics beyond the standard model of elementary particles. A series of outstanding observational results from experiments world-wide have given us an enviable insight into the properties of the arguably the most elusive and elementary particle – the neutrino. The most recent observation was the discovery of the mixing angle called θ_{13}. Despite these significant break-throughs made in the understanding of the neutrino, we still do not have a complete understanding of this mysterious particle. The goal of next generation neutrino experiments is to shed light further light on neutrino parameters such as the so-called neutrino mass hierarchy and the leptonic CP phase.

The India-based Neutrino Observatory (INO) is a mega-science project in India. The objective of this project is to develop an underground laboratory in India. The first detector to be built at this facility will be the ICAL detector which has been designed to observe atmospheric neutrinos. Amongst the main physics goals of this experiment is the measurement of the neutrino mass hierarchy as well as the precision measurement of the atmospheric neutrino oscillation parameters. My research in the past year has been heavily in understanding of the physics potential of this experiment and how to optimize it.

The relatively large measured value of θ_{13} has opened up the possibility of determining the neutrino mass hierarchy through earth matter effects. Amongst the current accelerator-based experiments only NOvA has a long enough baseline to observe earth matter effects. However, NOvA is plagued with uncertainty on the knowledge of the true value of δ_{CP}, and this could drastically reduce its sensitivity to the neutrino mass hierarchy. The earth matter effect on atmospheric neutrinos on the other hand is almost independent of δ_{CP}. The 50 kton magnetized Iron CALorimeter at the India-based Neutrino Observatory (ICAL@INO) will be observing atmospheric neutrinos. The charge identification capability of this detector gives it an edge over others for mass hierarchy determination through observation of earth matter effects. We studied in detail the neutrino mass hierarchy sensitivity of the data from this experiment simulated using the Nuance based generator developed for ICAL@INO and folded with the detector resolutions and efficiencies obtained by the INO collaboration

from a full Geant4-based detector simulation. The data from ICAL@INO is then combined with simulated data from T2K, NOvA, Double Chooz, RENO and Daya Bay experiments and a combined sensitivity study to the mass hierarchy is performed. We showed that with 10 years of ICAL@INO data combined with T2K, NOvA and reactor data, one could get about $2.3\sigma - 5.7\sigma$ discovery of the neutrino mass hierarchy, depending on the true value of $\sin^2\theta_{23}$ [0.4 – 0.6], $\sin^2 2\theta_{13}$ [0.08 – 0.12] and δ_{CP} [0 – 2π].

Precise measurement of the neutrino oscillation parameters is another physics goal for the ICAL@INO experiment. Using the detector resolutions and efficiencies obtained by the INO collaboration from a full-detector GEANT4-based simulation, we determined the reach of this experiment for the measurement of the atmospheric neutrino mixing parameters ($\sin^2\theta_{23}$ and $|\Delta m^2_{32}|$). We also explored the sensitivity of this experiment to the deviation of θ_{23} from maximal mixing, and its octant.

In another work we presented the results of a Monte Carlo simulation study of the hadron energy response (for 1 GeV $\leq$ E $\leq$ 15 GeV) of ICAL. Using a GEANT4 modeling of the ICAL detector, interactions of atmospheric neutrinos with target nuclei were recorded. We developed a method of calibration of the hadron energy using the hadron hit multiplicity in the active detector element. We first studied the detector response with single pions propagating through the detector. Then the average response of hadrons produced in atmospheric neutrino interactions was analyzed using NUANCE-generated neutrino events. The shape of the distribution and an appropriate fitting function were examined in detail. Finally, the hadron energy resolution was determined as a function of energy. We found an energy resolution of around (60–40)% for hadron energies in the range 2–15 GeV.

Neutrinos could be Majorana particles. If that was indeed the case then we expect to see the signature of its Majorana nature through the process where a nucleus could decay into another emitting two beta particles and no neutrinos. This process is known as neutrinoless double beta decay. In a recent work we discussed the possibility of neutrinoless double beta decay and lepton flavor violating decays such as $\mu- > e\gamma$ in the so-called colored seesaw scenario. In this mechanism, neutrino masses are generated at one-loop via the exchange of TeV-scale fermionic and scalar color octets. The same particles mediate lepton number and flavor violating processes. We showed that within this framework a dominant color octet contribution to neutrinoless double beta decay is possible without being in conflict with constraints from lepton flavor violating processes. We furthermore

compared the "direct" color octet contribution to neutrinoless double beta decay with the "indirect" contribution, namely the usual standard light Majorana neutrino exchange. For degenerate color octet fermionic states both contributions are proportional to the usual effective mass, while for non-degenerate octet fermions this feature is not present. Depending on the model parameters, either of the contributions can be dominant.

Publications:

1. Sandhya Choubey, Michael Duerr, Manimala Mitra (Gran Sasso), Werner Rodejohann, *Lepton Number and Lepton Flavor Violation through Color Octet States* JHEP **1205**, 017, (2012)

2. Anushree Ghosh, Tarak Thakore, Sandhya Choubey, Amol Dighe, *Determining the Neutrino Mass Hierarchy with INO, T2K, NOvA and Reactor Experiments,* JHEP **1304**, 009, (2013)

3. Anushree Ghosh, Tarak Thakore, Sandhya Choubey, Amol Dighe, *The Reach of INO for Atmospheric Neutrino Oscillation Parameters,* JHEP **1305**, 058, (2013)

Preprints:

1. Moon Moon Devi, Anushree Ghosh, Daljeet Kaur, Lakshmi S. Mohan, Sandhya Choubey, Amol Dighe, D. Indumathi, Sanjeev Kumar, M.V.N. Murthy, Md. Naimuddin, *Hadron energy response of the ICAL detector at INO,* arXiv:1304.5115

Conference/Workshops Attended:

1. *The XXV International Conference on Neutrino Physics and Astrophysics (Neutrino 2012)*, Japan, June, 2012.

2. *What is nu?: From new experimental neutrino results to a deeper understanding of theoretical physics and cosmology*, Florence, Italy, June, 2012.

Visits to other Institutes:

1. GGI - Galileo Galilei Institute for Theoretical Physics, Florence, Italy, June, 2012,

Invited Lectures/Seminars:

1. *Future of Atmospheric Neutrino Measurements*, plenary talk, The XXV International Conference on Neutrino Physics and Astrophysics (Neutrino 2012), Kyoto, Japan, June, 2013.

Other Activities:

1. Organizing schools/conferences:
   (a) Member of the International Advisory Committee, XIV International Workshop on Neutrino Telescopes, Venice, Italy, March 2013.
2. Teaching at HRI:
   (a) "Math Methods II", January semester, 2012.
   (b) First part of "Numerical Methods", August semester, 2012.
3. Mentoring PhD Students:
   (a) Anushree Ghosh
   (b) Ram Lal Awasthi
   (c) Deepak Tiwari
   (d) Aloke Sinha
4. Mentoring Project Students:
   (a) Souvik Dutta, Birla Institute of Technology & Science – Goa, Zuarinagar
5. Thesis Examination for a Ph.D. degree
   - Examined the Ph.D. thesis of Sushant Raut from IIT, Bombay.
6. Reviewing Papers: Refereed papers for
   (a) Physical Review D
   (b) Journal of High Energy Physics
7. Committees Served:
   (a) Office and Furniture Committee (Convenor)
   (b) Women Grievance Cell (Convenor)

Tapas Kumar Das

Research Summary:

During the academic year 2012 - 2013, I had been working on the Hawking like effects in relativistic acoustic geometry, astrophysics of our Galactic centre, and the influence of the spin angular momentum of a Kerr black hole on phase topologies of matter at very close proximity of the event horizon.

Publications

1. Hung-Yi Pu, Ishita Maity, **Tapas K Das** & Hsiang-Kuang Chang, *On Spin Dependence of Relativistic Acoustic Geometry*, Classical and Quantum Gravity **Volume 29, Issue 24, pp. 245020**, (2012)

2. **Tapas K. Das**, Sankhasubhra Nag, Swathi Hegde, Sourav Bhattacharya, Ishita Maity, Bożena Czerny, Paramita Barai, Paul J. Wiita, Vladimír Karas & Tapan Naskar, *Behaviour of low angular momentum relativistic accretion close to the event horizon*, Monthly Notices of Royal Astronomical Society **(To Appear)**, arXiv:1211.6952 [astro-ph.HE], (2013)

3. Bożena Czerny, Vladimír Karas, Devaky Kunneirath & **Tapas K. Das**, *Mini-spiral as source of material for Sgr A* in bright state*, Feeding Compact Objects: Accretion on All Scales, Proceedings of the International Astronomical Union, IAU Symposium, Cambridge University Press, **290, 199**, (2013)

4. Pratik Tarafdar & **Tapas K. Das**, *Dependence of acoustic surface gravity on geometric configuration of matter for axisymmetric background flow in the Schwarzschild metric*, Physical Review D **(under review)**, `arXiv:1305.7134 [gr-qc]`, (2013)

5. Bożena Czerny, Devaky Kunneirath, Vladimír Karas, & **Tapas K. Das**, *Multiple accretion events as a trigger for Sagittarius A* activity*, Astronomy & Astrophysics **(Volume 555, id.A97, DOI 10.1051/0004-6361/201118124)**, (2013)

Conference/Workshops Attended:

1. *DST-SERC School on Nonlinear Dynamics*, India, November - December 2012.

Visits to other Institutes:

1. Year long visit at the Theory Group, S. N. Bose National Centre for Basic Sciences, Kolkata, India, as a Sabbatical visitor during the period December 2012 - December 2013.

Invited Lectures/Seminars:

1. *Emergent Gravity Phenomena in the Classical and the Quantum Fluids*, a six lecture course with duration of two hours for each lecture at Ramkrishna Mission Vivekananda University, Kolkata, India, during September - October 2012.

2. *Black Hole at Your Bathtub*, Colloquium at PAMU, Indian Statistical Institute, Kolkata, November, 2012.

3. *Black Hole Accretion: A Dynamical Systems Approach*, an invited two lecture series delivered at DST-SERC School on Nonlinear Dynamics, India, held during November - December 2012.

Other Activities:

1. Mentoring Students

   (a) Parth Paul (DST Inspire Fellow), 1^{st} year M.Sc. student from Ramkrishna Mission Vivekananda University, Kolkata. Supervised at S N Bose National Centre Kolkata, during my stay at S N Bose National Centre as a Sabbatical Visitor.

   (b) Rupak Mukherjee (DST Inspire Fellow), 1^{st} year M.Sc. student from Ramkrishna Mission Vivekananda University, Kolkata. Supervised at S N Bose National Centre Kolkata, during my stay at S N Bose National Centre as a Sabbatical Visitor.

   (c) Anindita Dutta (West Bengal Govt. Special Merit Fellow), 1^{st} year M.Sc. student from Ramkrishna Mission Vivekananda University, Kolkata. Supervised at S N Bose National Centre Kolkata, during my stay at S N Bose National Centre as a Sabbatical Visitor.

   (d) Ankita Sarkar (DST Inspire Fellow), 1^{st} year M.Sc. student from Ramkrishna Mission Vivekananda University, Kolkata. Supervised at S N Bose National Centre Kolkata, during my stay at S N Bose National Centre as a Sabbatical Visitor.

(e) Tanusree Mondal, 1^{st} year M.Sc. student from Indian School of Mines, Dhanbad. Supervised at S N Bose National Centre Kolkata, during my stay at S N Bose National Centre as a Sabbatical Visitor.

(f) Deepika Anand (DST Inspire Fellow), 1^{st} year M.Sc. student from IISER Pune. Supervised at S N Bose National Centre Kolkata, during my stay at S N Bose National Centre as a Sabbatical Visitor. Deepika also visited (her second project with me after the first one was completed during my stay at S N Bose National Centre Kolkata) at HRI.

(g) Sayani Ghosh, 2^{nd} year B.Sc. student from Mount Carmel College, Bangalore.

(h) Aarti Singh, B.Tech. student from Delhi College of Engineering.

(i) Pratik Tarafdar, 1^{st} year Ph.D. student from S, N, Bose National Centre (Registered with Prof. A. S. Majumdar of S. N. Bose National Centre), Kolkata. We submitted a paper (`arXiv:1305.7134 [gr-qc]`) and are working on two more projects, one with Deepika Anand, who will be visiting HRI for a longer term.

Aditi Sen De

Research Summary:

Quantifying quantum correlations plays an important role in the development of quantum information science. There are several ways in which the quantification is possible. The concept of monogamy is an important binding theme for quantum correlations of states shared between several quantum systems. Monogamy arises due to the fact that bipartite quantum correlations of states of three or more quantum systems are usually such that if two of the parties are highly quantum correlated, these parties have little or no quantum correlations with any other party. Monogamy is not expected to be satisfied by a classical correlation measure of a multiparty quantum state. It is known that sharing entanglement between several parties is restricted by the monogamy of entanglement. We take over the concept of monogamy to an information-theoretic quantum correlation measure, and find that it violates monogamy in general. We quantify the feature using the concept of discord monogamy score. We find a necessary condition of a vanishing discord monogamy score for arbitrary three-party states. A necessary and sufficient condition is obtained for pure states. We prove that the class of states having a vanishing discord monogamy score cannot have arbitrarily high genuine multipartite entanglement, as quantified by generalized geometric measure. In the special case of three-qubit pure states, their classification with respect to the discord monogamy score reveals a rich structure that is different from that which had been obtained by using the monogamy score corresponding to the entanglement measure called concurrence.

A measure of quantum correlation defined from an information-theoretic perspective, namely, quantum discord, is applied to study the time-evolved nonequilibrium state of the infinite anisotropic quantum XY spin chain in a transverse time-dependent field. In particular, we probe whether the collapse and revival of nearest-neighbor entanglement of the state seen with a varying initial applied field strength, at a fixed evolution time, may be predicted from the behavior of the quantum correlation measure. For this quantum many-body system, realizable with currently available technology, we find that the revival of entanglement of the evolved state happens if there is an increase in quantum discord in the vicinity of entanglement collapse. Moreover, we find opposite statistical-mechanical behaviors of the two major paradigms in which quantum correlation measures are defined, viz., the entanglement-separability paradigm and the information-

theoretic one. We show this by considering the ergodic properties of such quantum correlation measures in transverse quantum XY spin-1/2 systems in low dimensions. While entanglement measures are ergodic in such models, the quantum correlation measures defined from an information-theoretic perspective can be nonergodic.

The quantum spin ladder is an interesting platform to investigate quantum many body systems in the intermediate sector between the one- and two-dimensional lattice structures. The possibility of relating doped even-legged quantum spin ladders to high-temperature superconductivity make such quantum systems extremely important. A striking feature of the quantum spin ladder is that the interpolation from the 1-D spin chain to the 2-D square lattice by gradually increasing the number of legs is not straightforward. For example, the quantum characteristics of the Heisenberg ladder ensures that the odd- and the even-legged ladder ground states have different correlation properties. We introduce an analytical iterative method, the density matrix recursion method, to generate arbitrary reduced density matrices of superpositions of short-ranged dimer coverings on periodic or non-periodic quantum spin-1/2 ladder lattices, with an arbitrary number of legs. The method can be used for calculating bipartite as well as multipartite physical properties, including bipartite and multipartite entanglement. We apply this technique to distinguish between even- and odd-legged ladders. Specifically, we show that while genuine multipartite entanglement decreases with increasing system-size for the even-legged ladder states, it does the opposite for odd-legged ones.

Publications:

1. H.S. Dhar, R. Ghosh, A. Sen(De), and U. Sen, *Quantum Discord Surge Heralds Entanglement Revival in an Infinite Spin Chain,* Europhys. Lett. **98**, 30013 (2012).

2. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Conditions for Monogamy of Quantum Discord: Monogamous Greenberger-Horne-Zeilinger versus Polygamous W states,* Phys. Rev. A **85**, 040102(R) (2012).

3. A. Sen(De), and U. Sen, *Locally Accessible Information of Multisite Quantum Ensembles Violates Monogamy,* Phys. Rev. A **85**, 052103 (2012).

4. M.N. Bera, R. Prabhu, A. Sen(De), and U. Sen, *Characterization of Tripartite Quantum States with Vanishing Monogamy Score,* Phys. Rev. A **86**, 012319 (2012).

5. A. Sen(De) and U. Sen, *Entanglement Mean Field Theory and the Curie-Weiss Law,* Europhys. Lett. **99**, 20011 (2012).

6. R. Prabhu, A. Sen(De), and U. Sen, *Dual quantum correlation paradigms exhibit opposite statistical mechanical properties,* Phys. Rev. A **86**, 012336 (2012).

7. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Relating monogamy of quantum correlations and multisite entanglement,* Phys. Rev. A **86**, 052337 (2012).

8. H.S. Dhar, A. Sen(De), and U. Sen, *Density Matrix Recursion Method: Genuine Multisite Entanglement Distinguishes Odd from Even Quantum Heisenberg Ladders*, New Journal of Physics **15**, 013043 (2013).

9. R. Nepal, R. Prabhu, A. Sen(De), and U. Sen, *Maximally-dense-coding-capable quantum states,* Phys. Rev. A **87**, 032336 (2013).

Preprints:

1. Salini K., R. Prabhu, A. Sen (De), and U. Sen, *All Multiparty Quantum States Can Be made Monogamous,* arXiv:1206.4029 [quant-ph].

2. U. Mishra, A. Sen(De), and U. Sen, *Macroscopic Schrödinger Cat Resistant to Particle Loss and Local Decoherence,* arXiv: 1206.4029 [quant-ph].

3. R. Prabhu, A. Sen(De), and U. Sen, *Genuine Multiparty Quantum Entanglement Suppresses Multiport Classical Information Transmission,* arXiv:1208.6535 [quant-ph].

4. M.N. Bera, R. Prabhu, A. Sen(De), and U. Sen, *Multisite Entanglement acts as a Better Indicator of Quantum Phase Transitions in Spin Models with Three-spin Interactions,* arXiv:1209.1523 [quant-ph].

5. A. Biswas, R. Prabhu, A. Sen(De), and U. Sen, *Genuine Multipartite Entanglement Trends in Gapless-gapped Transitions of Quantum Spin Systems,* arXiv:1211.3241 [quant-ph].

6. H.S. Dhar, A. Sen(De), and U. Sen, *Genuine Multipartite Entanglement Trends in Gapless-gapped Transitions of Quantum Spin Systems*, arXiv: 1211.3877 [quant-ph].

7. K. Rama Koteswara Rao, A. Sen(De), U. Sen, H. Katiyar, T.S. Mahesh, A. Kumar, *Monogamy of quantum correlations reveals frustration in quantum Ising spin system: Experimental demonstration*, arXiv:1301:1834 [quant-ph].

8. M.N. Bera, R. Prabhu, A. Sen(De), and U. Sen, *Limit on Time-Energy Uncertainty with Multipartite Entanglement,* arXiv:1303.0706 [quant-ph].

9. U. Mishra, R. Prabhu, A. Sen(De), and U. Sen, *Tuning interaction strength leads to ergodic-nonergodic transition of quantum correlations in anisotropic Heisenberg spin model,* arXiv:1303.3821 [quant-ph]

Conference/Workshops Attended:

1. *Symposium on Physics using the HPC facility*, India, August, 2012.

2. *DAE-BRNS Symposium on Atomic, Molecular and Optical Physics*, India, December 2012.

3. *International Conference On Quantum Information and Quantum Computing (ICQIQC)*, India, January 2013.

Visits to other Institutes:

1. Indian Institute of Science Education and Research Kolkata, India, December 2012.

2. Indian Institute of Technology Delhi, India, January 2013.

Invited Lectures/Seminars:

1. *Quantum Correlation for Quantum Technologies*, Symposium on Physics using the HPC facility, HRI, Allahabad, August 2012.

2. *Multiparty quantum correlations and its application in quantum communication*, DAE-BRNS Symposium on Atomic, Molecular and Optical Physics, IISER Kolkata, Kolkata, December 2012.

3. *Interplay of Quantum Correlations in Many-body Systems*, International Conference On Quantum Information and Quantum Computing (ICQIQC), IISC, Bangalore, January 2013.

Other Activities:

1. Taught a regular course on "Quantum Information and Computation" during Aug-Dec 2012.
2. Mentored master projects of Tamoghna Das and Dibya Mukherjee.
3. Mentored numerical projects of Tamoghna Das, Dibya Mukherjee, Debasis Sadhukhan and Sudipto Singha Roy.
4. Mentored a summer student, Salini K, IISER Trivandrum.
5. Member of national organizing committee of International Conference on Quantum Information and Quantum Computing (ICQIQC), January 2013.
6. Served as a convener of the Housing Committee, and members of the Physics Graduate Committee, the Pantry and Guest House Committee, the Horticulture Committee, and the Women Grievances Cell.
7. Served as referees in national and international journals.

Rajesh Gopakumar

Research Summary:

In the last year my investigations have been largely on the duality between the higher spin gravity theories on AdS_3 and solvable CFTs in two dimensions. This is an interesting case of the AdS/CFT correspondence involving (in many cases) nonsupersymmetric quantum field theories and can potentially teach us more about this correspondence in a new setting. With M. Gaberdiel, we clarified the nature of the symmetry algebra on the bulk side and the nontrivial matching with the higher spin symmetry of the 2d CFT. The important observation is that the bulk classical symmetry algebra is deformed at the quantum level in a very nontrivial way. With Gaberdiel, we also wrote an invited review on this duality between 2d minimal model CFTs and higher spin theories on AdS_3.

We have been further pursuing various interesting directions in this general topic in the last year. One such direction is that of embedding these higher spin theories in string theory. To this end, we have looked at an example with a large amount of supersymmetry which constrains the choices significantly. Gaberdiel and I have recently proposed a duality between a 2d coset theory with the so-called large $\mathcal{N} = 4$ supersymmetry and a corresponding higher spin theory. We have also seen indications in this case that a non-abelian version of the higher spin theory in AdS_3 might be equivalent to a string theory on $AdS_3 \times S^3 \times S^3 \times S^1$ (which also has this large amount of SUSY). Identifying the corresponding coset theory is an important question for the future. This will also help in identifying the string dual to the model of strange metals in one spatial dimensions that we have investigated (with A. Hashimoto, I. Klebanov, S. Sachdev and K. Schoutens). Here too the field theory was a so-called stringy coset which had a central charge proportional to N^2 rather than N (in the large N limit).

With M. Gaberdiel and M. Rangamani, we have also been investigating whether or not there is any kind of phase transition in the original W_N minimal models at finite temperature. This is a difficult technical problem and we have employed a combination of numerical and analytical techniques. So far, however the results seem to suggest there is no phase transition. Along different lines, with my student Roji Pius, I have also been following up on the earlier investigation on the "simplest gauge-string duality". We have computed arbitrary planar correlation functions in the simple Gaussian matrix model. This is to be compared with physical correlators in the A-model topological string theory on P^1 which we also computed.

We found complete agreement of two and three point functions. For more general correlators, we found a simple relation between the two which could be understood in terms of additional contact terms in the topological string theory which are absent in the matrix model and need to be therefore corrected for.

Publications:

1. M. Gaberdiel, R. Gopakumar, *Triality in Minimal Model Holography*, JHEP **1207**, 127 (2012).

2. R. Gopakumar, A. Hashimoto, I. Klebanov, S. Sachdev and K. Schoutens, *Strange Metals in One Spatial Dimension*, Phys. Rev. D **86**, 066003 (2012).

3. M. Gaberdiel, R. Gopakumar, *Minimal Model Holography*, Invited review for special issue of J. Phys. A (to appear).

4. R. Gopakumar, R. Pius, *Correlators in the Simplest Gauge-String Duality*, JHEP **1303**, 175 (2013).

Preprints:

1. M. Gaberdiel and R. Gopakumar, *Large N=4 Holography*, arXiv:1305.4181 [hep-th].

Conference/Workshops Attended:

1. *Workshop on Higher Spin Theory*, Schrodinger Institute, Vienna, Apr. 2012.

2. *Workshop on Strings, Branes and M-theory*, Newton Instt., Cambridge, UK, May 2012.

3. *Discussion Meeting on String Theory*, ICTS-TIFR Bangalore, Jun. 2012.

4. *Amsterdam workshop on String Theory*, Univ. of Amsterdam, Jul. 2012.

5. *Scattering Amplitudes, Gauge Theories and String theories*, ICTS-TIFR, Bangalore, Sep. 2012.

6. *Indian String School*, Puri, Oct. 2012.

7. *Yukawa International Seminar (YKIS)*, Kyoto University, Oct. 2012.
8. *New Trends in Field Theory*, Benares Hindu University, Varanasi, Nov. 2012.
9. *IRCMS meeting*, Bose Institute, Kolkata, Nov. 2012.
10. *Indian Strings Meeting 2012*, Puri, Dec. 2012.
11. *ICTS Discussion Meeting on String Theory*, TIFR-Mumbai, Jan. 2013.
12. *Bangkok Workshop on Gauge Theory, String Theory and Gravity*, Chulalongkorn University, Bangkok, Jan. 2013.
13. *Second Solvay Workshop on Higher Spin Theories*, Solvay Institutes, Brussels, Feb. 2013.
14. *UGC Winter School on High Energy Physics*, BHU, Varanasi, Feb. 2013.

Visits to other Institutes:

1. Schrodinger Institute, Vienna, Apr. 2012.
2. Newton Instt., Cambridge, UK, May 2012.
3. Durham University, UK, May 2012.
4. North Bengal University, May 2012.
5. IACS, Kolkata, Jun. 2012.
6. ICTS-TIFR Bangalore, Jun. 2012.
7. Univ. of Amsterdam, Jul. 2012.
8. ICTS-TIFR Bangalore, Sep. 2012.
9. Kyoto University, Oct. 2012.
10. Lucknow University, Nov. 2012.
11. Benares Hindu University, Nov. 2012.
12. Bose Institute, Kolkata, Nov. 2012.
13. TIFR, Mumbai, Jan. 2013.

14. Chulalongkorn University, Bangkok, Jan. 2013.

15. ULB-Solvay Institute, Brussels, Feb. 2013.

16. Benares Hindu University, Feb. 2013.

Invited Lectures/Seminars:

1. *Triality in Minimal Model Holography*, Workshop on Higher Spin Theory, Schrodinger Institute, Vienna, Apr. 2012.

2. *Who's Afraid of Higher Spin theories?*, Newon Instt. Silver Jubilee Lecture, Dept. of Maths. Durham University, UK, May 2012.

3. *Triality in Minimal Model Holography*, Workshop on Strings, Branes and M-theory, Newton Instt., Cambridge, UK, May 2012.

4. *String Theory and the Quest for Quantum Spacetime*, Seminar, North Bengal University, May 2012.

5. *String Theory and the Quest for Quantum Spacetime*, A. K. Raychaudhuri Memorial Lecture, IACS, Kolkata, Jun. 2012.

6. *What Can We Lean from Coset CFTs and their Duals?*, Amsterdam workshop on String Theory, Univ. of Amsterdam, Jul. 2012.

7. *Spacetime without Scattering*, Scattering Amplitudes, Gauge Theories and String theories, ICTS-TIFR, Bangalore, Sep. 2012.

8. *Minimal Model Holography*, (four lectures), Indian String School, Puri, Oct. 2012.

9. *What Can We Lean from Coset CFTs and their Duals?*, Yukawa International Seminar (YKIS), Kyoto University, Oct. 2012.

10. *Spacetime and String Theory*, (two lectures), Lucknow University, Oct. 2012.

11. *What Can We Lean from Coset CFTs and their Duals?*, New Trends in Field Theory, Benares Hindu University, Varanasi, Nov. 2012.

12. *String Theory and the Quest for Quantum Spacetime*, IRCMS Colloquium Talk, Bose Institute, Kolkata, Nov. 2012.

13. *What Can We Lean from Coset CFTs and their Duals?*, (Plenary Review Talk), Indian Strings Meeting 2012, Puri, Dec. 2012.

14. *The Simplest Gauge-String Duality*, (two lectures), Bangkok Workshop on Gauge Theory, String Theory and Gravity, Chulalongkorn University, Bangkok, Jan. 2013.

15. *What Can We Lean from Coset CFTs and their Duals?*, Second Solvay Workshop on Higher Spin Theories, Solvay Institutes, Brussels, Feb. 2013.

16. *Gauge-String Dualities*, (three lectures), UGC Winter School on High Energy Physics, BHU, Varanasi, Feb. 2013.

Academic recognition/Awards:

- Delivered Isaac Newon Institute Silver Jubilee Lecture at Durham University, UK.
- Delivered A. K. Raychaudhuri Memorial Lecture, IACS Kolkata.

Other Activities:

1. Co-Organiser, ICTS Discussion Meeting on String Theory, Bangalore, Jun. 2012.
2. Member, National Steering Committee for SERC school in theoretical high energy physics, (2011- present).
3. Member, International Advisory Committee, Bangkok Workshop on Gauge Theory, String Theory and Gravity, 2013 and 2014.
4. Chair of Parallel Session on Strings and Branes at 20th International Conference on General Relativity and Gravitation (GR20) at Warsaw University, Jul. 2013.
5. Delivered general talk ”Electric-Magnetic Duality and Ashoke” at Felicitation Ceremony for Ashoke Sen, HRI, Jul. 2012, and at Presidency University, Dec. 2012.
6. Member/convenor of various academic and administrative committees at HRI.

Dileep P. Jatkar

Research Summary:

In the last one year, I have been working on relation between Stochastic quantization and holographic Wilsonian renormalization group in AdS/CFT. We first established the dictionary between these two approaches and demonstrated that it works by studying a couple of examples which possessed Weyl invariance. We have now managed to extend this to conformally coupled scalars. For conformally coupled scalar our procedure works in any dimensions.

Publications:

1. J.-H. Oh and D. P. Jatkar, *Stochastic quantization and holographic Wilsonian renormalization group*, JHEP **11** 144 (2012) arXiv:1209.2242 [hep-th].

Preprints:

1. D. P. Jatkar and J.-H. Oh, *Stochastic quantization of conformally coupled scalar,* in preparation

Conference/Workshops Attended:

1. *CERN workshop on string theory*, Switzerland, June 2012,
2. *Meeting on Amplitudes*, India, September 2012,
3. *ISM 2012*, India, December 2012,
4. *Topical meeting on String Theory*, India, January 2013.

Visits to other Institutes:

1. CERN, Geneva,Switzerland, June-July 2012,
2. ICTS, Bangalore, India, September 2012,
3. Department of Physics, North Bengal University, Siliguri, India, October 2012,
4. IISER, Pune, India, January 2013,

5. TIFR, Mumbai, India, January 2013.

Invited Lectures/Seminars:

1. *Stochastic Quantization and AdS/CFT*, Meeting on Amplitudes, ICTS, Bangalore, September 2012.
2. *Group Theory for Particle Physics*, SERC Preparatory School, NBU, Siliguri, October 2012.
3. *Stochastic Quantization and AdS/CFT*, ISM 2012, HRI-Utkal Univ, Puri, December 2012.
4. *SU(2) gauge theory on AdS_4*, Seminar IISER, Pune, January 2013.
5. *Black Hole Microstate Counting*, Topical meeting on String theory, TIFR, Mumbai, January 2013.

Other Activities:

1. Convener, Physics Graduate Committee, 2012-13.

Anshuman Maharana

Research Summary:

I joined the institute on the 1st of November 2012; since then I have worked on string phenomenology - the area of string theory which aims at making contact with particle physics and cosmology. Models of particle physics arising from branes at singularities were analysed in detail; various phenomenological aspects such supersymmetry breaking and flavour structure were explored. On the cosmological side, preliminary work to construct models of quintessence was carried out.

Publications:

1. Anshuman Maharana and Eran Palti, *Models of Particle Physics from Type IIB String Theory and F-theory.* International Journal of Modern Physics A **Vol. 28** (2013).

Conference/Workshops Attended:

1. *Indian Strings Meeting 2013*, India, December 2012.
2. *Strings to LHC-III Conference*, India, December 2012.
3. *Particle Physics at the Crossroads, Edinburgh Delhi Particle Physics Symposium*, India, January 2013.

Invited Lectures/Seminars:

1. *Lecture Series on Model Building in type IIB String Theory*, Invited talk at Strings to LHC-III Conference, Puri, India, December 2012.
2. *String Phenomenology: An Overview*, Invited talk at Particle Physics at the Crossroads, Edinburgh Delhi Particle Physics Symposium, Delhi, January 2013.

Academic recognition/Awards:

- Ramanujan Fellowship of Department of Science and Technology, 2012.

Pinaki Majumdar

Research Summary:

With my students I have been working on problems related to (i) the interplay of geometric frustration and electron correlation in itinerant systems, (ii) the effect of disorder in superconductors, and (iii) the competetion between magnetism and superconductivity close to a Mott transition.

Publications:

1. Pinaki Majumdar and Sabyasachi Tarat, *Pairing fluctuations, the BCS-BEC crossover, and strong disorder in superconductors,* Journal of Superconductivity and Novel Magnetism **26**, 1787, (2013)

2. Rajarshi Tiwari and Pinaki Majumdar, *Visualizing the Mott transition,* Current Science, **103**, 518, (2012)

3. Rajarshi Tiwari and Pinaki Majumdar, *Noncollinear magnetic order in the double perovskites: double exchange on a geometrically frustrated lattice,* IJMPB **27**, 1350018, (2013)

Preprints:

1. Rajarshi Tiwari and Pinaki Majumdar, *The crossover from a bad metal to a frustrated Mott insulator,* arXiv:1301.5026

2. Rajarshi Tiwari and Pinaki Majumdar, *Mott transition and glassiness in the face centered cubic lattice,* arXiv:1302.2922

Conference/Workshops Attended:

1. *International Conference on Superconductivity and Magnetism 2012*, Istanbul, Turkey, April 2012

2. *Indo-Japan Conference*, Bangalore, India, October 2012.

3. *Frontiers of Condensed Matter Physics*, Delhi, India, March 2013.

Visits to other Institutes:

1. Tata Inst of Fundamental Research, Mumbai, India, September 2012.

Invited Lectures/Seminars:

1. *Pairing fluctuations, the BCS-BEC crossover and strong disorder in superconductors*, ICSM Conference, Istanbul, Turkey, April 2012.

2. *Visualizing many body physics*, Institute Colloquium, TIFR Mumbai, September 2012.

3. *Spectroscopic signatures of a metal on the verge of a Mott transition*, Indo-Japan Meeting, IISc Bangalore, October 2012.

4. *Understanding correlated fermions: the test case of the Mott transition*, National Seminar, Delhi University, March 2013.

Other Activities:

1. Served in the KVPY selection at HRI, Jan 2013.

Biswarup Mukhopadhyaya

Research Summary:

Almost immediately after the announcement of a Higgs-like boson at the Large Hadron Collider (LHC) experiment, we carried out an intensive study on the trace of possible non-standard behaviour of this boson. This styudy, the first of its kind from India, and one of the most general investigations of its kind world-wide, included the possible effects of invisible Higgs decay, absorptive phases in top-pair effective amplitude, departure from custodial SU(2) symmetry and several other novel features. A detailed statistical analysis of data, together with the theoretical calculation of various new physics effects, embdied a set of rather sugggestive conclusions. (S. Banerjee, S. Mukhopadhyaya, B. Mukhopadhyaya)

A supersymmetric (SUSY) model that was accommodated light dark matter was investigated, including both cosmologival and collider issues. In particular, novel signals involving tau-lepton pairs was suggestef for the LHC. (G. Belanger, Sanjoy Biswas, C. Boehm, B. Mukhopadhyaya)

An inverse seesaw scenario is one where Majorana masses for the neutrinos arise from small lepton-number violating effects. A SUSY scenario answering to such an effect was investigated, using a hitherto unprecedented blend of SUSY parameters that have their origin at high or low scale. Some predictable observables at the LHC was predicted. (P.S. Bhupal Dev, S. Mondal, B. Mukhopadhyaya, S. Roy)

A new signal of an isosinglet top-like quark can lead to new signals at the LHC, especially because such a quark can decay via flavour-changing neutral current interactoin as well as through flavour-changing Yukawa couplings. Some such signals, focusing on the identification of multiple b-quark pair peaks, was identified. The recent announcement that the HIggs boson is perhaps there around 125 GeV adds to the viability of such signals. A study of how to distinguish such top-like quarls from bottom-like ones is also done. (A. Girdhar, B. Mukhopadhyaya, M. Patra)

Publications:

1. P.S. Bhupal Dev, Subhadeep Mondal, Biswarup Mukhopadhyaya, Sourov Roy, *Phenomenology of Light Sneutrino Dark Matter in cMSSM/mSUGRA with Inverse Seesaw,* JHEP **1209**, 110, (2012)

2. Shankha Banerjee, Satyanarayan Mukhopadhyay, Biswarup Mukhopad-

hyaya, *New Higgs interactions and recent data from the LHC and the Tevatron,* JHEP **1210**, 062, (2012)

3. Genevieve Belanger, Sanjoy Biswas, Celine Boehm, Biswarup Mukhopadhyaya, *Light neutralino dark matter in the MSSM and its implication for LHC searches for staus*, JHEP **1212**, 076, (2012)

4. Nishita Desai, Biswarup Mukhopadhyaya, *Constraints on supersymmetry with light third family from LHC data,* JHEP **1205**, 057, (2012)

5. Biswarup Mukhopadhyaya, Somasri Sen, Soumitra SenGupta, *Matter-gravity interaction in a multiply warped braneworld,* J. Phys. **G40**, 015004, (2013)

6. Paramita Dey, Biswarup Mukhopadhyaya, Sourov Roy, Sudhir K. Vempati, *Constraints on axino warm dark matter from X-Ray observation at the Chandra telescope and SPI,* JCAP **1205**, 042, (2012)

Preprints:

1. Aarti Girdhar, Biswarup Mukhopadhyaya , *A clean signal for a top-like isosinglet fermion at the Large Hadron Collider,* arXiv:1204.2885 [hep-ph]

2. Debajyoti Choudhury, Rashidul Islam, Anirban Kundu, Biswarup Mukhopadhyaya, *Anomalous Higgs Couplings as a Window to New Physics,* arXiv:1212.4652 [hep-ph]

Conference/Workshops Attended:

1. *Higgs-top Meeting*, Indian Institute of Science, Bangalore, August, 2013.

2. *Recent Trends in High Energfy Physics: golden Jubilee celebration of the Institute of Mathematical Sciences*, Chennai, December, 2012.

3. *UGC sponsored school on particle physics*, Banaras Hindu University, January-February, 2013.

4. *Higgstop-13*, BITS, Goa, February, 2013.

Visits to other Institutes:

1. *University of Hawaii, Honolulu, USA,* March - April, 2012.
2. *Tata Institute of Fundamental Research, Mumbai,* April-May, 2012.
3. *Indian Association for the Cultivation of Science,* May-June, 2012.
4. *IISER, Bhopal,* June, 2012.
5. *Indian Institute of Science, Bangalore,* August, 2012.
6. *Indian Institute of Technology, Gauhati,* August, 2012.
7. *Jamia Milia University, Delhi*, September, 2012.
8. *Kalyani University, West Bengal*, September, 2012.
9. *Jangipur College, West Bengal*, November, 2012.
10. *Institute of Mathematical Sciences, Chennai,* December, 2012.
11. *Banaras Hindu University, Varanasi*, January, 2013.
12. *BITS, Goa*, February, 2013.
13. *Jawaharlal Nehru University, Delhi,* March, 2013.

Invited Lectures/Seminars:

1. *New physics with low missing energy at the LHC: identification and discrimination*, High Energy Physics Seminar, University of Hawaii, Honolulu, April, 2012.
2. *The Higgs Boson saga*, Physics Colloquium, University of Hawaii, Honolulu, April, 2012.
3. *Events with low missing energy at the LHC*, Theoretical Physics Colloquium, Tata Institute of Fundamental Research, Mumbai, May, 2012.
4. *The world of the very small: symmetries, surprises and searches*, INSPIRE Invited Lecture, Indian Institute of Science Education and Research, Bhopal, June, 2012.
5. *Current data and the possibility of non-standard Higgs couplings*, Invited talk at the Conference on the Higgs boson and the Top Quark, Indian Institute of Science, Bangalore, August, 2012.

6. *The Higgs Boson saga as told in August 2012*, Physics Colloqium, Indian Institute of Technology, Gauhati, August, 2012. *The God particle: myth and reality*, Public Lecture, Allahabad Museum, August, 2012.

7. *The Higgs Boson saga as told in September 2012*, Physics Colloqium, Jamia Milia University, Delhi, September, 2012.

8. *The Higgs Boson saga and the God particle myth*, Public Lecture, Kalyani University, West Bengal, September, 2012.

9. *The Higgs Boson saga and the God particle myth*, Public Lecture, Jangipur College, West Bengal, November, 2012.

10. *The Higgs Boson and beyond*, Golden Jubilee Celebration Lecture, Institute of Mathematical Sciences, Chennai, December, 2012.

11. *The story of the Higgs Boson*, Science Conclave Invited Lecture, Indian Institute of Information Technology, Allahabad, December, 2012.

12. *Higgs physics, the standard model and beyond*, Series of three lectures in the UGC sponsored school on particle physics, Banaras Hindu University, January-February, 2013.

13. *The Higgs Boson saga*, Public Lecture, BITS, Goa, February, 2013.

14. *Life with the Higgs Boson and after*, Physics Colloquium, Jawaharlal Nehru University, Delhi, March, 2013.

Other activities:

Served as Co-ordinator, Regional Centre for Accelerator-based Particle Physics (RECAPP), Harish-Chandra Research Institute.

G. Venketeswara Pai

Research Summary:

My research focuses on two class of problems : the effect of electronic correlations in solids and low dimensional systems. Using the two-fluid (*l-b*) model of manganites and a modified coherent potential approximation that takes into account the renormalization of Jahn-Teller energy and resultant mixing of both electronic states in a selfconsistent way, we studied the effect of hybridization between itinerant and localized electrons. Another problem involves the study of spin wave excitations in the A-type metallic manganites and the magnon induced orbital fluctuations that can arise in such systems. We have also looked at the magnetic phase separation in orbitally degenerate double-exchange systems using both mean field theory and exact numerical simulations. The second set of problems involves strategies to develop pure spin currents using mesoscopic quantum wire networks by tuning Aharanov-Bohm flux threading them, intrinsic Dresselhaus spin-orbit (SO) coupling, and Rashaba SO interaction arising due to gate voltage and we plan to extend it to look at the effect of disorder and time varying fields.

Recently, we have started looking at the competition between superconductivity and charge density wave phases using a real space based, numerically exact procedure. This would give us information about the strong coupling behavior and effect of nonmagnetic and magnetic disorder. Kinetic induced non-coplanar magnetic phases in double perovskites is another problem we are currently exploring. The nature of superconductivity in topological insulators and indirect band gap semiconductors is another area that is being explored. The Josephseon effect in spinor Bose condensates is being pursued.

Preprints:

1. *Effect of Hybridization in the l-b Model of Doped Manganites*
   with Saurabh Pradhan
   (in preparation)

2. *Tunable Spin Filtering using a Quantum Wire Network*
   with Sanjoy Datta and T. P. Pareek
   (in preparation)

3. *Magnetic Phase Separation in Orbitally Degerate Double-Exchange Sys-*

tems
with Saurabh Pradhan and Sayan Basak
(in preparation)

Visits to other Institutes:

1. Dept. of Physics, Indian Institute of Science, Bangalore, January 2013
2. Sree Kerala Varma College, Trissur, January 2013
3. Dept. of Physics, Banaras Hindu University, Varanasi (several times during Oct 2012 to Feb 2013)

Invited Lectures/Seminars:

1. A series of talks given at Sree Keral Varma College, Trissur on "*Correlated Electrons in Solids*" and "*Cold Atom Cendensates*", January 2013

Other Activities:

1. Guided a VSP project student (Academy Summer Research Fellow), Jishnu Nampoothiri (IISER, TVM) during May-July 2012.
2. Guided the project of a first year student, Ajanta Maity, during Jan-May 2012.
3. Taught a first year graduate course, Statistical Mechanics, during Jan-May 2012.
4. Taught an advanced graduate course, Quantum Many Body Theory (CMP III), during Jan-May 2013.
5. Convener of the Library committee and member of the Physics PDF-Visitors' committee and Cluster Computing Facility committee.

Sudhakar Panda

Research Summary:

We studied the possibility of explaining the late time acceleration with an axion eld which is coupled with the dark matter sector of the energy budget of the Universe. The axion eld arises from the Ramond-Ramond sector of the Type-IIB string theory as constructed by Panda etal. We investigated the background evolution of the Universe as well as the growth of the matter perturbation in the linear regime. We subsequently use the observational data from Sn-Ia, BAO measurements, measurements of the Hubble parameter as well as the observational data for the growth of the matter perturbation to constrain our model. Our results show that coupled axion models are allowed to have larger deviation for the equation of state parameter from cosmological constant by the present observational data.

Investigation is on constructing Inflationary models keeping R^2 term in the gravitational action which can be equivalently described by a scalar field with a potential. When a matter scalar field is coupled to this action, it results in a two-field inflationary model.

Publications:

1. A. Bhattacharjee, A. Das, L. Greenwood and S. Panda, *Motion of a test particle in the transverse space of Dp-branes,* Int. J. Mod. Phys.**D21**, 1250056, (2012)

Preprints:

1. S. Kumar, S. Panda and A.A.Sen,*Cosmology with Axionic-quintessence Coupled with Dark Matter,* 1302.1331 [astro-ph.CO]

Conference/Workshops Attended:

1. *Current Trends in High Energy Physics*, BHU, Varanasi, India, 2012.
2. *ISM-2012*, Puri, India, December, 2012.
3. *From Strings to LHC III*, Puri, India, December, 2012.

4. *Edinburgh Delhi Particle Physics Symposium*, New Delhi, India, February 2013.

5. *IAGRG Meeting*. Pauri, Sringar, India, 2013.

6. *Discussion Meeting on Dark Energy*, TIFR, Mumbai, India, March 2013.

Visits to other Institutes:

1. Assam University, Silchar, India, March, 2013.

2. TIFR, Mumbai, India, March 2013.

Invited Lectures/Seminars:

1. *Some Aspects of String Cosmology*, Edinburgh Delhi Particle Physics Symposium, NewDelhi, February 2013.

2. *Inflation and Quitessence in String Theory*, Current Trends in High Energy Physics, BHU Varanasi, 2012 .

Other Activities:

1. Dean, Administration, from May, 2009.

2. Local Works Committee, from August, 2012.

3. Member, Purchase Committee, from August, 2012.

4. Member, Monitoring Committee for Construction work in HRI, 2011-13.

5. Member, Board of Studies, CTP, Jamia Univ, Delhi. 2011.

6. Organizer, ISM-12 Meeting, December 2012.

7. Organizer, Discussion Meeting on Dark Energy at HRI, November, 2012.

8. Referee of Research articles for JHEP, JCAP , Phys. Rev. D and Journal of Astro Physics and Cosmology.

9. Member, Executive Council, Central University of Orissa.

Tribhuvan Prasad Pareek

Research Summary:

We have studied and developed a transport theory for non-abelian fluids. In particular we have developed a non-equilibrium density matrix formulation for Quantum coherent spin transport. Using the concept of vectorial matrices and complex vectors (bivectors) and quaternion we are able to obtain analytical expression for scattered density matrix. Using this density matrix spin conservation and charge conservation are formulated. Its consequences for unitarity of scattering matrix in spin space are discussed and its relevance for non-abelian hydrodynamics is being studied. Our approach is valid for one channel as well many channel case. In many channel system with spin-orbit coupling, our problem has a close similarity with the multichannel Kondo problem. This aspect is being pursued for further studies with Trilochan Bagarati. Multichannel Kondo problem is also the subject matter of our Indo-French project entitled "Correlation and transport far from equilibrium in nano-system ". For this we are developing the NEGF based approach to handle transport in mesoscopic Kondo systems.

Preprints:

1. *T.P. Pareek, Generalized unitarity and Quantum coherent Charge and Spin Transport, manuscript under preparation*

2. *Analytical NEGF model for Quantum spin transport, Trilochan Bagarati and T. P. Pareek, Manuscript under preparation*

Other Activities:

1. I have taught CMP1 course in our graduate programme and have been member of various adminstration comm.

Arun Kumar Pati

Research Summary:

My research during this academic year is mainly focused on understanding of quantum correlation in composite systems. We have investigated the role of quantum discord in uncertainty relation. Also, we have given a physical basis for quantum correlations by showing that whenever we erase quantum correlation that has some thermodynamic cost. Further, we have introduced a notion of super quantum discord using the theory of weak measurements.

Entropic Uncertainty Relation and Quantum Discord Uncertainty relations capture the essence of the inevitable randomness associated with the outcomes of two incompatible quantum measurements. Recently, Berta et al. have shown that the lower bound on the uncertainties of the measurement outcomes depends on the correlations between the observed system and an observer who possesses a quantum memory. If the system is maximally entangled with its memory, the outcomes of two incompatible measurements made on the system can be predicted precisely. Here, we obtain a new uncertainty relation that tightens the lower bound of Berta et al., by incorporating an additional term that depends on the quantum discord and the classical correlations of the joint state of the observed system and the quantum memory. We discuss several examples of states for which our new lower bound is tighter than the bound of Berta et al. On the application side, we discuss the relevance of our new inequality for the security of quantum key distribution and show that it can be used to provide bounds on the distillable common randomness and the entanglement of formation of bipartite quantum states.

Physical Cost of Erasing Quantum Correlation Erasure of information stored in a quantum state requires energy cost and is inherently an irreversible operation. If quantumness of a system is physical, does erasure of quantum correlation as measured by discord also need some energy cost? Here, we show that change in quantum correlation is never larger than the total entropy change of the system and the environment. The entropy cost of erasing correlation has to be at least equal to the amount of quantum correlation erased. Hence, quantum correlation can be regarded as genuinely physical. We show that the new bound leads to the Landauer erasure. The physical cost of erasing quantum correlation is well respected in the case of bleaching of quantum information, thermalization, and can have potential application for any channel leading to erasure of quantum

correlation.

Enhancement of Geometric Phase by Frustration of Decoherence: A Parrondo like Effect
Geometric phase plays an important role in evolution of pure or mixed quantum states. However, when a system undergoes decoherence the development of geometric phase may be inhibited. Here, we show that when a quantum system interacts with two competing environments there can be enhancement of geometric phase. This effect is akin to Parrondo like effect on the geometric phase which results from quantum frustration of decoherence. Our result suggests that the mechanism of two competing decoherence can be useful in fault-tolerant holonomic quantum computation

Super Quantum Discord with Weak Measurements
Weak measurements cause small change to quantum states, thereby opening up the possibility of new ways of manipulating and controlling quantum systems. We ask, can weak measurements reveal more quantum correlation in a composite quantum state? We prove that the weak measurement induced quantum discord, called as the "super quantum discord", is always larger than the quantum discord captured by the strong measurement. Moreover, we prove the monotonicity of the super quantum discord as a function of the measurement strength. We find that unlike the normal quantum discord, for pure entangled states, the super quantum discord can exceed the quantum entanglement. Our result shows that the notion of quantum correlation is not only observer dependent but also depends on how weakly one perturbs the composite system.

Publications:

1. Arun Kumar Pati, Mark M. Wilde, A. R. Usha Devi, A. K. Rajagopal, Sudha, *Quantum discord and classical correlation can tighten the uncertainty principle in the presence of quantum memory* , Physical Review A **86**, 042105 (2012)

2. Subhashish Banerjee, C. M. Chandrashekar, Arun K. Pati, *Enhancement of Geometric Phase by Frustration of Decoherence: A Parrondo like Effect* , Phys. Rev. A **87**, 042119 (2013)

3. R. Prabhu, Arun Kumar Pati, Aditi Sen De, Ujjwal Sen *Light Cone-Like Behavior of Quantum Monogamy Score and Multisite Entanglement*, Phys. Rev. A **86**, 052337 (2012)

Preprints:

1. Arun K. Pati, *Physical Cost of Erasing Quantum Correlation,* arXiv:1208.4804

2. Uttam Singh, Arun Kumar Pati, *Super Quantum Discord with Weak Measurements*, arXiv:1211.0939

Invited Lectures/Seminars:

1. *Monogamy of Quantum Correlation*, Quantum and Nano Computing Advanced School (QANSAS 2012) from Nov. 29-Dec 2, 2012 in DEI, Agra.

2. *Quantum Correlations are Physical*, INTERNATIONAL CONFERENCE ON QUANTUM INFORMATION AND QUANTUM COMPUTING (IC-QIQC), IISC, Bangalore 7-11, Jan 2013.

Academic recognition/Awards:

- Elected Fellow of the Indian Academy of Science, Bangalore in 2013.
- K. P. Chair Professor of Zheijiang University, China.

Other Activities:

1. Serving as member of various committees of HRI.

2. Chief Editor of Journal of Quantum Information Sceince.

Santosh Kumar Rai

Research Summary:

I joined the institute in October 2012. My current area of research is on new ideas beyond the Standard Model (SM) of particle physics. I have been working on models of extended gauge symmetries, supersymmetric theories and their implications in collider experiments such as the Large Hadron Collider (LHC). In particular, I studied a non-supersymmetric model where the gauge symmetry is given by $SU(5) \times SU(3)' \times SU(2)' \times U(1)'$ which is broken down to the Standard Model gauge symmetry at the TeV scale. This leads to new leptoquark gauge bosons at the TeV scale. We studied its possible signatures at the LHC and underlined the search strategies for its discovery. The CMS Collaboration at the LHC is looking for such particles and our study has a direct relevance to their search strategies. I have also been working on extensions of the $SU(2)_L$ gauge symmetry in the SM by an $SU(2)_R$ gauge symmetry which we call a left-right mirror-symmetry but unlike the usual left-right models where the SM fermions are charged under the new symmetry, here each left handed SM fermion multiplet is accompanied by new right handed fermion multiplet of opposite chirality. Therefore instead of having right handed multiplets for each left handed multiplets of the same fermions as in the usual left-right model, the mirror model include right handed doublets involving new fermions (called mirrors), and similarly for each right handed singlet, there are corresponding mirror singlets. We are studying the collider implications of such particles at the LHC.

Publications:

1. S. Chakdar, T. Li, S. Nandi, Santosh Kumar Rai, *Top SU(5) Models: Baryon and Lepton Number Violating Resonances at the LHC,* Phys.Rev. **D87**, 096002, (2013).

Preprints:

1. S. Chakdar, K. Ghosh, S. Nandi, Santosh Kumar Rai., *Collider signatures of mirror fermions in the framework of Left Right Mirror Model* (in preparation).

Conference/Workshops Attended:

1. *HIGGSTOP-2013*, India, February 2013.

Invited Lectures/Seminars:

1. *Coloured Exotics at the Large Hadron Collider*, HIGGSTOP-2013, BITS-Pilani (Goa Campus), Goa, February 2013.

Other Activities:

1. Member, Organising Committee of *Sangam @ HRI : Instructional Workshop in Particle Physics*, March 2013.

2. Mentoring *Numerical Projects* of two students: Kasinath Das and Krashna Mohan Tripathi, 2013.

Sumathi Rao

Research Summary:

During the period, April 2012-March 2013, I continued my research in the areas of topological insulators and non-abelian anyons.

More specifically, we have looked at the transport of gapless Dirac fermions on hyperbolic surfaces. We showed that independent of the curvature of the hyperbolae and the sharpness of the corners, no backward scattering takes place and transmission of the topological surface states is completely independent of the geometrical shape of the surface. The density of states of the electrons, however, shows a dip at concave step edges which can be measured by an STM tip. We also show that the tunneling conductance measured by a polarized scanning tunneling probe exhibits an unconventional dependence on the polar and azimuthal angles of the magnetization of the tip as a function of the curvature of the surface and the sharpness of the edge.

We are now studying the effect of including electron-electron interactions to see how they affect transport and density of states at the corners.

We have also looked at the recent proposal of photonic topological insulators, where either by using CROWs (coupled resonator optical waveguides) or metamaterials, the idea has been to get topologically protected edge states in photonic systems, which can then be used for constructing qubits with fault tolerant operations. In this context, we have been studying the edge states of the Hofstadter model to which the optical resonator models can be mapped.

We have now also started looking at topological field theories as opposed to the topological band theories we were studying earlier. One motivation for this, is the possibility of including effects of strong electron-electron interactions. Some kinds of exotic excitations such as monopoles and dyons also have a more natural framework in terms of the Chern-Simons field theories which have been studied in high energy physics for many years.

Publications:

1. P. Shastry, R. Ramaswamy, S. Narasimhan, S. Rao, S. Ubale and S. Kulkarni, *Gender diversity in physics in India: Interventions so far and recommendations for the future*, Proceedings of the 4th International IUPAP Conference on Women in Physics, (2012).

2. Abhiram Soori, Sourin Das and Sumathi Rao,*Magnetic field induced Fabry-Perot resonances in helical edge states*, Phys. Rev. **B86**, 125312 (2012).

Preprints:

1. Udit Khanna, Saurabh Pradhan and Sumathi Rao, *Transport and STM studies of hyperbolic surface states of topological insulators*, cond-mat/1303.3700, to be published in Phys. Rev. **B**.

2. Udit Khanna and Sumathi Rao, *Edge states in the Hofstadter model and relationship with photonic topological insulators*, (in preparation).

3. Aditya Banerjee, Udit Khanna and Sumathi Rao, *Luttinger liquids on curved edges*, (in preparation).

Conference/Workshops Attended:

1. Pre-Workshop Brainstorming session on Role of Women Scientists, NASI, Allahabad Sept 15, 2012.

2. New Trends in Field Theories, Dept. of Physics, BHU, Varanasi, 23 - 26 Nov, 2012.

Visits to other Institutes:

1. ICTS, Bangalore, June 4 - 27 July 2012.

Invited Lectures/Seminars:

1. *Topological insulator and effect of magnetic field on surface states*, Dept. of Physics, BHU, Nov 25, 2012.

2. *Gender and science*, seminar at Allahabad University, 2nd March 2013.

3. *Topological insulators*, colloquium, Panjab University, Chandigarh, March 11, 2013.

Other Activities:

1. Acting director, May 2011 - May 2012.
2. Convenor, Faculty advisory committee.
3. Member, Local works committee, housing committee and Plan committee.
4. Member, Academic council, Motilal Nehru Institute of Information Technology, Allahabad.
5. Taught mesoscopic physics, Aug 2012-Dec 2012.
6. Taught quantum mechanics 2, Jan 2013-May 2013.

Ashoke Sen

Research Summary:

My work during the period April 2012 - March 2013 can be divided into three categories.
Together with Sayantani Bhattacharyya and Binata Panda I studied logarithmic corrections to the entropy of extremal Reissner-Nordstrom black holes. Later I generalized this to compute logarithmic corrections to the entropy of non-extremal black holes. Similar techniques were then used to compute logarithmic correction to the free energy of M-theory on $AdS_4 \times X$, and compare this with the microscopic results (with Sayantani Bhattacharyya, Alba Grassi and Marcos Marino).
Together with Abhishek Chowdhury, Shailesh Lal and Arunabha Saha, I studied the fate of the bound states of two black holes in N=4 supergravity as we move in the moduli space of the theory. We found a specific transition from one bound state to another across a one dimensional supspace of the moduli space – called black hole bound state metamorphosis. This was necessary for consistency between the microscopic and the microscopic results.
In two papers with Jan Manschot and Boris Pioline, I used our earlier results on multi-black hole bound states to derive an explicit formula for the cohomology of quiver moduli spaces in terms of a set of constants known as single centered degeneracy.

Publications:

1. S. Bhattacharyya, B. Panda and A. Sen, "Heat Kernel Expansion and Extremal Kerr-Newmann Black Hole Entropy in Einstein-Maxwell Theory," JHEP **1208** (2012) 084 [arXiv:1204.4061 [hep-th]].

2. A. Sen, "Logarithmic Corrections to Schwarzschild and Other Non-extremal Black Hole Entropy in Different Dimensions," arXiv:1205.0971 [hep-th].

3. J. Manschot, B. Pioline and A. Sen, "From Black Holes to Quivers," JHEP **1211** (2012) 023 [arXiv:1207.2230 [hep-th]].

4. A. Chowdhury, S. Lal, A. Saha and A. Sen, "Black Hole Bound State Metamorphosis," JHEP **1305** (2013) 020 [arXiv:1210.4385 [hep-th]].

5. S. Bhattacharyya, A. Grassi, M. Marino and A. Sen, "A One-Loop Test of Quantum Supergravity," arXiv:1210.6057 [hep-th].

6. J. Manschot, B. Pioline and A. Sen, "On the Coulomb and Higgs branch formulae for multi-centered black holes and quiver invariants," JHEP **1305** (2013) 166 [arXiv:1302.5498 [hep-th]].

Invited Lectures/Seminars at Schools/Conferences:

1. Progress in Quantum Field Theory and String Theory, Osaka, April 3-7, 2012
2. Joint IIP-ICTP Workshop on Gravity and String Theory, Sao Paolo, Brazil, May 8-9, 2012
3. IIP-ICTP School on Gravity and String Theory, Natal/RN-Brazil, May 10-24, 2012.
4. Black Holes and Information, KITP, Santa Barbara, May 21-25.
5. Discussion meeting on string theory, ICTS, Bangalore, Jun 11-22, 2012.
6. String Math 2012, University of Bonn, Germany, July 16-21, 2012.
7. Discussion meeting on scattering without space-time, ICTS, Bangalore, Sep 24-28, 2012.
8. The Holographic Way: Gauge Theory, String Theory and Black Holes, NORDITA, Stockholm, October 15-18, 2012.
9. Indian Strings meeting, Puri, India, December 16-21, 2012.
10. Golden Jubilee Conference, IMSc, Chennai, Jan 2 - 4, 2013.

Courses given at HRI:

1. Quantum Field Theory 2, August-December, 2012
2. Atomic, Molecular and Nuclear Physics, January-May, 2013

Awards and Distinctions:

1. Fundamental Physics Prize, 2012
2. D.Sc. (Hon), Panjab University, 2013

Prasenjit Sen

Research Summary:

My research activities during this period focussed on first-principles electronic structure studies of atomic clusters, 2-dimensional (2D) electronic materials and bulk oxides. In atomic clusters, we studied the geometric and electronic structures of small rhodium clusters. We also continued our studies on 3d transition metal alkaline earth clusters. We identified $CrSr_9$ and $MnSr_{10}$ as new magnetic superatoms. In 2D materials, we studied properties of structural defects in hybrid h-BN graphene sheets. We also studied electronic properties of the so-called spin-gapless semiconductor material Co-doped $PbPdO_2$.

Publications:

1. V. Chauhan and P. Sen, *Electronic and magnetic properties of 3d transition metal-doped strontium clusters: Prospective magnetic superatoms,* Chemical Physics **417**, 37, (2013)

2. P. Srivastava and P. Sen, *Density functional study of structural defects in h-BNC_2 sheets,* Journal of Physics: Condensed Matter **025304**, 025304, (2013)

3. M. Beltran, F. Buendia, V. Chauhan, P. Sen, H. Wang, Y. J. Ko, and K. Bowen, *Electronic, magnetic and structural properties of Rh_n ($n = 1 - 9$) clusters: Joint ab initio and anion photoelectron studies,* European Physical Journal D **67**, 63, (2013)

Preprints:

1. S. Haldar, P. Srivastava, O. Eriksson, P. Sen and B. Sanyal, *Diffusion and magnetism of Fe nanostructures on 2D hybrids of graphene and h-BN,* (in preparation).

2. P. Srivastava, B. J. Nagare, D. G. Kanhere, and P. Sen, *Electronic structure of the spin gapless material Co-doped $PbPdO_2$,* (submitted).

3. V. Chauhan, A. Singh and P. Sen, *Density functional studies of transition metal aluminum clusters: Role of shell model and aromaticity in stability,* (in preparation).

Conference/Workshops Attended:

1. *International Symposium on Science of Clusters, Nanoparticles and Nanoscale Materials*, India, March 2013.
2. *Electronic structure approaches to Atoms, Molecules, Clusters and Solids*, India, Januray 2013.
3. *Theme Meeting on 2D Nanostructures: Graphene and Beyond*, India, July 2012.

Visits to other Institutes:

1. Virginia Commonwealth University, Richmond VA, USA, June 2012.

Invited Lectures/Seminars:

1. *Transition metal doped group-II and group-III metal clusters: shell model and superatoms*, International Symposium on Science of Clusters, Nanoparticles and Nanoscale Materials, Central University Rajasthan, Jaipur, March 2013.
2. *Electronic structure of TM-Sr clusters: new magnetic superatoms*, Electronic structure approaches to Atoms, Molecules, Clusters and Solids, University of Hyderabad, Hyderabad, January 2013.
3. *Defects and ad-atoms on h-BNC sheets*, Theme Meeting on 2D Nanostructures: Graphene and Beyond, Indian Institute of Science, Bangalore, July 2012.

Academic recognition/Awards:

- Selected Regural Associate, ICTP, Trieste for 2012-2017.

Other Activities:

1. Reviewed manuscripts for the journals Physical Chemistry Chemical Physics and Applied Physics Letters.
2. Acted as the nodal person at HRI for the Garuda Grid throughout the year.
3. Taught part of the course on Numerical methods.

4. Mentored visiting undergraduate (VSP), graduate students and post-docs.

Anirban Basu

Research Summary:

I am currently working on problems related to scattering amplitudes in superstring theory. These amplitudes, coupled with the properties of U–duality for maximally supersymmetric theories, contain non–trivial information about various interactions in the low energy effective action, even at the non–perturbative level. My aim is to understand them in the context of type IIB string theory in 10 dimensions.

Conference/Workshops Attended:

1. *Mathematics and Applications of Branes in String and M-theory*, Newton Institute, Cambridge, UK, March–April, 2012

2. *IIP-ICTP School on Gravity and String Theory*, Natal, Brazil, May 2012.

Invited Lectures/Seminars:

1. *Supersymmetry constraints on the R^4 multiplet in type IIB on T^2*, Newton Institute, Cambridge, UK, April 2012.

2. *Supersymmetry constraints on the R^4 multiplet in type IIB on T^2*, IIP-ICTP , Natal, Brazil, May 2012.

Shrobona Bagchi

Research Summary:

Remote state preparation in relativistic scenario: We present remote state preparation to a scenario, where the receiver is moving with constant velocity with respect to the sender in one case and with an uniform acceleration in another. In this setting we show how the fidelity of the state that is prepared in moving frame decreases with respect to velocity, in cases of maximally as well as non-maximally entangled states. Also we make use of entanglement amplification beyond the single mode approximation to see if fidelity can be improved in case of an accelerated observer.

Quantum correlating capability of nonlocal hamiltonian: One of the most important goals of quantum information and computation is to exploit the quantum correlations of the states for performing different exotic quantum information processing tasks. Thus it is necessary to know under what conditions we can produce or increase the amount of quantum correlations given an initial state. Apart from entanglement, there are other measures of quantum correlations as well. One of them is the quantum discord. We propose to quantify the quantum discord via the entanglement change between the local density matrices and the purified version of the same. Using this relation, as well as independently, we see how does the quantum correlation of states change under the action of nonlocal Hamiltonian.Thus we present here analytical as well as numerical results of the correlating capacities on the nonlocal Hamiltonian.

Monogamy of mutual information and the entanglement of purification: In quantum world sharing of entanglement between several parties is restricted by the monogamy of entanglement. Though general quantum correlation measures are expected to obey monogamy,they are not. We ask, does monogamy of a correlation measure qualify it to be called as a quantum correlation? The answer is no. We find that the quantum mutual information for any tripartite pure entangled states always respects monogamy, yet it is not a measure of quantumness. We find a necessary and sufficient condition in terms of interaction information for tripartite mixed state when the mutual information will respect monogamy. There are other measures of total correlation like the entanglement of purification. We study here the conditions for monogamy of the entanglement of purification, and its relation with the entanglement of formation. We find a new lower bound for the entanglement of purification and the regularised entanglement of purification. We show that the entanglement of

purification is nonincreasing upon discarding of quantum systems. We also present some conditions for monogamy in terms of the entropic inequalities, along with numerical results.

Preprints:

1. Arun.k.Pati and Shrobona Bagchi, *Monogamy of mutual information and entanglement of purification*(in preparation)

Conference/Workshops Attended:

1. *International conference on quantum information and quantum computing (ICQIQC)*, India, January 2013.

Other Activities:

1. Tutorship for the course Quantum Information and Computation(QIC) taken by Dr.Aditi Sen De, August-December, 2012.

Shankha Banerjee

Research Summary:

During this academic year, I have worked on the possibility of Beyond Standard Model (BSM) physics by looking at the allowed departure of the higgs couplings to fermions and bosons, from their Standard Model expectations. I have also tried to see what percentage of invisble branching ratio of the higgs boson is still allowed by the present data. Here, I have considered the recent most data from the LHC and the Tevatron. I have done a global fit allowing upto 7 parameters to study the coupling departures.

I have also worked on the invisible higgs decay in a Supersymmeric Inverse Seesaw Model. Here I worked on the possibility of the lightest higgs in this model, decaying invisibly to a pair of sneutrino LSPs (lightest supersymmetric particle), giving a missing energy signature. I performed a two-parameter global fit to find the optimal invisible branching ratio of the lightest higgs in this model. Here, I performed a detailed cut-based analysis to check the viability of our signal when compared to the backgrounds, in context of the LHC.

Publications:

1. Shankha Banerjee, Satyanarayan Mukhopadhyay, Biswarup Mukhopadhyaya, *New Higgs interactions and recent data from the LHC and the Tevatron,* JHEP **10**, 062, (2012)

Preprints:

1. Shankha Banerjee, P.S. Bhupal Dev, Subhadeep Mondal, Biswarup Mukhopadhyaya, Sourov Roy, *Invisible Higgs Decay in a Supersymmetric Inverse Seesaw Model with Light Sneutrino Dark Matter,* arXiv:1306.2143 [hep-ph]

Conference/Workshops Attended:

1. *Across the TeV Frontier with the LHC*, Cargese, France, August 20-September 1, 2012,

2. *Frontiers in High Energy Physics 2012 Symposium*, Chennai, India, December 10-13, 2012,

3. *HiggsStop-2013*, Goa, India, February 25-27, 2013,

4. *Sangam @ HRI*, Allahabad, India, March 25-30, 2013.

Visits to other Institutes:

1. Indian Association for the Cultivation of Science, Kolkata, India, December 17-21, 2012,

2. Indian Association for the Cultivation of Science, Kolkata, India, April 14-22, 2013.

Invited Lectures/Seminars:

1. *New Higgs interactions and recent data from the LHC and the Tevatron*, Seminar at Cargese School, Across the TeV Frontier with the LHC, Cargese, France, August 21, 2013.

Other Activities:

1. Teaching assistant for Mathematical Methods I course, August-December, 2012.

Atri Bhattacharya

Research Summary:

During the academic year 2012–2013, I worked on studying how some of the properties of neutrino mixing hitherto not well understood might be seen in future long baseline and atmospheric neutrino experiments. To this end, under the guidance of my supervisor, Raj Gandhi, and along with two collaborators, Animesh Chatterjee and Mehedi Masud, we have developed a code that calculates the neutrino events expected to be seen in a detector once the detector's specifics and the atmospheric neutrino fluxes are detailed in the code. We combine the results of the atmospheric neutrino experiment with the 1300 Km long baseline neutrino experiment proposed to be set up at FERMILAB to explore the neutrino mass hierarchy, the octant of the mixing angle θ_{23} and to test the existance of CP violation in the three family neutrino sector due to the CP violating phase $\delta_{\rm CP}$. We have seen that the combination of atmospheric neutrino events and events from the beam experiment provide heightened sensitivities to almost all the physics questions we have attempted to resolve. This is as yet work-in-progress, but we plan to submit a preprint soon.

Visits to other Institutes:

1. The International Centre for Theoretical Physics, Trieste, Italy, November 2012,
2. University of Würzburg, Würzburg, Germany, November 2012,
3. Max Planck Institute for Nuclear Physics, Heidelberg, Germany, November 2012,
4. University of California-Riverside, Riverside, California, United States of America, March 2013,
5. University of Wisconsin-Madison, Madison, Wisconsin, United States of America, March 2013,
6. Ohio State University, Columbus, Ohio, United States of America, March 2013,
7. University of Arizona, Tucson, Arizona, United States of America, April 2013,

8. University of California-Los Angeles, Los Angeles, California, United States of America, April 2013.

Saurabh Pradhan

Research Summary:

Manganites: The substitution of oxygen isotope in these systems is known to give rise to a metal- insulator transition and large changes in the ferromagnetic Curie temperature. Using the two fluid model and incorporating the hybridization effects between the two classes of electrons comprising it, we study the isotope effect using a modified coherent potential approximation (CPA) that also includes the renormalization of Jahn-Teller energy in a self-consistent way. Another problem that I am working on is the spin wave spectrum of metallic A- type manganites and magnon induced orbital fluctuations in them. Parallely, I have been working on the anisotropic magnetc phases in orbitally degenerate double-exchange model and the effect of Coulomb interaction on nanoscale phase separation in manganites within the two-fluid model using exact diagonalization based Monte Carlo algorithm. **Corner States in Quantum Hall Systems:** Edge states play an important role in giving rise to quantum Hall states in two dimensional electron gas and graphene. In rectangular geometry, in addition to these edge states , we expect localized electronic states at the corner. Currently we are studying the properties of such states and ways to observe this experimentally.

Publications:

1. *Transport and STM studies of hyperbolic surface states of topological insulators*, with Udit Khanna and Sumathi Rao, Phys. Rev. B **87**, 245411 (2013).

Conference/Workshops Attended:

- School on Modern Topics in Condensed Matter Physics, Singapore, February-2013.

Teaching assistant for the following course:

1. Numerical Methods (Instructor : Prasenjit Sen, Sandhya Choubey)

Vikas Chauhan

Research Summary:

Over the last year, we have done first principle study of TM@Sr_n, and TM@Al_n clusters. Doping of TM atom in these clusters provide us fascinating aspect of their electronic and magnetic properties. In TM@Sr_n clusters, we found $CrSr_9$ and $MnSr_{10}$ clusters are specially stable with finite moments. We have explained their stabilty in the frame of crystal field effect, also finite moment due to Hund's rule. Hence these two clusters offer new magnetic superatoms. Further our study for TM@Al_n clusters, where TM = Cr, Mn, Fe, Co showed enthralling results. For example we found $FeAl_4$ and $CoAl_3$ are very stable clusters as they are having 20 and 18 electrons. First we try to explain stability of these clusters in the frame of shell model, but their MO plots do not provide us such simple picture. Then we have applied concept of aromaticity which traditionally has been used for hydrocarbons. We have shown these metal clusters are aromatic in nature which is underlying reason of their stabilty. We have also done first principle study of V@Ag_n clusters, results are under proccess. Also we have been interested in hydrogentaion of TM@Al_n clusters, which offer us ligand stabilized cluster.

Publications:

1. Marcela R. Beltran, Fernando Buendia Zamudio, Vikas Chauhan, Prasenjit Sen, Haopeng Wang, Yeon Jae Ko, and Kit Bowen, Ab initio and anion photoelectron studies of Rhn (n = 19) clusters Eur. Phys.J.D **67**, 63, (2013)

2. Vikas Chauhan, Prasenjit Sen Electronic and magnetic properties of 3d transition metal-doped strontium clusters: Prospective magnetic superatoms Chemical Physics **417**, 37, (2013)

Conference/Workshops Attended:

1. *Quantum Monte Carlo and CASINO programm at Vallico Sotto, Tuscany*, Italy, 5th Aug-12th Aug, 2012.

2. *School and Workshop on electonic structure calculations with HPC systems at Naukuchiatal*, India, April 29 - May 4, 2013.

Other Activities:

1. As tutor for Atomic and Molecular physics, Jan - May, 2013.

Arunabha Saha

Research Summary:

$N = 4$ supersymmetric string theories contain negative discriminant states whose numbers are known precisely from microscopic counting formulæ. On the macroscopic side, these results can be reproduced by regarding these states as multi-centered black hole configurations provided we make certain identification of apparently distinct multi-centered black hole configurations according to a precise set of rules. We provide a physical explanation of such identifications, thereby establishing that multi-centered black hole configurations reproduce correctly the microscopic results for the number of negative discriminant states without any ad hoc assumption.

Publications:

1. Arunabha Saha, Abhishek Chowdhury, Shailesh Lal, Ashoke Sen, *Black Hole Bound State Metamorphosis,* JHEP **1305**, 020 , (2013)

Conference/Workshops Attended:

1. *Indian Strings Meet*, India, December 2012.

Invited Lectures/Seminars:

1. *Black Hole Bound State Metamorphosis / talk*, Indian Strings Meet, Puri, December 2012.

Abhishek Chowdhury

Research Summary:

During this academic year I have worked on a problem of mismatch in counting number of states in microscopic and macroscopic description of multicentered black holes in string theory which resulted in a publication. Presently I have been collaborating with two groups, one regarding the microscopic counting of a D-brane system and the later involves topological field theory, specifically BF theory.

Preprints:

1. Abhishek Chowdhury, Shailesh Lal, Arunabha Saha and Ashoke Sen, *Black Hole Bound State Metamorphosis,* arXiv:1210.4385

Conference/Workshops Attended:

1. *International School On Strings And Fundamental Physics*, Germany, July 2012.
2. *Advanced String School*, India, October 2012.
3. *From Strings to LHC - III*, India, December 2012.
4. *Indian String Meeting*, India, December 2012.
5. *Spring School on Superstring Theory and Related Topics ICTP*, Italy, March 2013.

Visits to other Institutes:

1. INFN, Rome, Italy, March 2112,
2. ETH, Zurich, Switzerland, March 2012.
3. NIKHEF, Amsterdam, Netherlands, March 2012.

Invited Lectures/Seminars:

1. *Black Hole Bound State Metamorphosis*, INFN, Rome, March 2012.
2. *Black Hole Bound State Metamorphosis*, ETH, Zurich, March 2012.

3. *Black Hole Bound State Metamorphosis*, NIKHEF, Amsterdam, March 2012.

Other Activities:

1. Tutored for Advanced Quantum Field Theory, August - December,2012.

Ujjal Kumar Dey

Research Summary:

During this academic year I have worked on the non-minimal Universal Extra Dimensional(nmUED) models where boundary localized terms(BLT), taken asymmetrically on the fixed points of the orbifold breaks the KK-parity making the lightest Kaluza-Klein particle(LKP) unstable. However symmetric BLTs preserve KK-parity. It has been shown from the recent dark matter(DM) relic density observations that the BLTs serve to relax the constraints set on the compactification scale in mUED. Present day precision measurements of DM properties help to constrain the BLT parameters. Depending on the parameter values, the LKP can be level-1 photon or the level-1 Z-boson. We find that the relic density of the later is too small to be a single component viable dark matter candidate. We also explore the prospects of direct detection of an LKP which matches the observed DM relic density.

In another work we study the implications of recent data on Higgs from LHC on UED and nmUED.

Publications:

1. Anindya Datta, Ujjal Kumar Dey, Avirup Shaw, Amitava Raychaudhuri, *Universal extra-dimensional models with boundary localized kinetic terms: Probing at the LHC,* Phys. Rev. D 87, 076002, (2013)

Preprints:

1. Ujjal Kumar Dey, Tirtha Sankar Ray, *Constraining minimal and non-minimal UED models with Higgs couplings,* arXiv:1305.1016 [hep-ph]

2. Anindya Datta, Ujjal Kumar Dey, Amitava Raychaudhuri, Avirup Shaw, *Boundary Localized Terms in Universal Extra-Dimensional models through a Dark Matter perspective,* arXiv:1305.4507 [hep-ph]

Conference/Workshops Attended:

1. *From Strings to LHC-III*, Puri, December, 2012.

2. *HIGGSTOP-2013*, Goa, February, 2013.

Ushoshi Maitra

Research Summary:

We explore the constraints on a Randall-Sundrum warped geometry scenario, where a radion field arises out of the attempt to stabilise the radius of the extra compact spacelike dimension. With this in view, the most recent data from the Large hadron Collider (LHC) and the Tevatron in the major Higgs search channels are used. Improving upton the previous studies, we perform a full analysis, taking into account the effect of various cuts that determine the contributions to various channels from the two scalar mass eigenstates arising from radion-Higgs kinetic mixing. The most important channel to be affected by this is the WW^* decay of the scalars, where no invariant mass peak can discern the decaying physical states. Interference effects, which sometime strenthen the constraints when two scalars are close in mass to each other, are also taken into account. The possibility of a relatively massive, radion-like, scalar decaying into a pair of Higgs-like scalars on the various event rates are also included. Based on a global anasysis of the current data, for not only the 125 GeV scalar but also scalars of various masses ranging from 110 to 600 GeV, we obtain the up-to-date exclusion contours in the parameter space. Side by side, the 95% confidence level regions, based on a χ^2 minimisation procedure, are also presented.

With the introduction of Gauss Bonnet term we are going to find the constraint over the vev of radion using the limits on mass of RS graviton.

Preprints:

1. Ushoshi Maitra, Nishita Desai, Biswarup Mukhopadhyaya, *An analysis of Radion-Higgs mixing in the light of recent higgs data,* (in preparation)

Conference/Workshops Attended:

1. *CTEQ-Fermilab School 2012*, Peru, July-August 2012,
2. *TOPHIGGS*, India, Februray 2013.

Visits to other Institutes:

1. IACS, Kolkata, India, June 2012

2. IACS, Kolkata, India, December 2012.

Saurabh Niyogi

Research Summary:

We work out strongly interacting sector of a non-minimal Universal Extra Dimension (nmUED) scenario with one flat extra spatial dimension in the presence of brane-localized kinetic and Yukawa terms. On compactification, these terms are known to have significant, nontrivial impact on the masses and the couplings of the Kaluza-Klein (KK) excitations. We study the masses of the level 1 KK gluon and the quarks and find the modified strong interaction vertices involving these particles. The scenario conserves KK parity. Possibility of significant level-mixing among the quarks from different KK-levels is pointed out with particular reference to the top quark sector. Cross sections for various generic final states involving level 1 KK-gluon and KK-quarks from first two generations are estimated at the Large Hadron Collider (LHC). The decay branching fractions of both strong and weakly interacting KK excitations are studied to estimate yields in various different final states involving jets, leptons and missing energy. These are used to put some conservative constraints on the nmUED parameter space using the latest LHC data. Nuances of the scenario are elucidated with reference to the minimal Universal Extra Dimension (mUED) and Supersymmetry (SUSY) and their implications for the LHC are discussed.

Publications:

1. AseshKrishna Datta, Kenji Nishiwaki, Saurabh Niyogi, *Non-Minimal Universal Extra Dimensions : The strongly Interacting sector at the Large Hadron Collider (LHC),* Journal of High Energy Physics (JHEP) **1211**, 154, (2012)

Conference/Workshops Attended:

1. *From Strings to LHC*, India, December, 2012.
2. *XX DAE-BRNS High Energy Physics Symposium*, India, January, 2013.
3. *HIGGSTOP-2013*, India, February, 2013.

Manoj Kumar Mandal

Research Summary:

Presently I am investigating the effect of parton showers(PS) for several important physics processes in the Standard Model(SM) and beyond the SM at next to leading order in Quantum Chromodynamics in order to get realistic predictions for the Large Hadron Collider(LHC). Currently the LHC has produced large amount of data which are being studied/analysed against the accurate theoretical predictions. To test the predictions of potential theories using various scattering processes, it is inevitable to include the higher order QCD radiative corrections, the main reason being their large observable effects at LHC. In addition, they are essential to reduce theoretical uncertainties arising from missing higher order quantum corrections through renormalisation and factorisation scales. The fixed order predictions are often not good enough to cover entire phase space of the physics processes and it is well known that the multi-particle final states in the collinear region can give observable effects which are hard to incorporate in fixed order computations due to technical difficulties. The parton showers can provide reasonable estimate of these effects in those kinematical regions. The most difficult task is to match the fixed order results and the parton showers in a consistent way so that the resultant one captures almost entire phase space accessible. Often next to leading order SM results supplemented with parton showering provide reliable as well as realistic predictions that can serve testing of various theoretical predictions. I have been involved in matching the parton shower at NLO for various processes at the LHC that are studied to test the predictions of the large extra dimension models namely the ADD model. The processes include production of di-bosons and di-leptons in the ADD model at the LHC. In addition, the study of three photon production process at LHC resulting from SM interactions is under way at NLO level taking into account showering effects. Recently, I have also been involved in setting up the machinary for chararterising the properties of newly discovered boson at the LHC which will shed light on its spin and parity.

Publications:

1. R. Frederix, Manoj K. Mandal, Prakash Mathews, V. Ravindran, Satyajit Seth, P. Torrielli, M. Zaro, *Diphoton production in the ADD model to NLO+parton shower accuracy at the LHC ,* JHEP **1212**, 102, (2012)

Preprints:

1. Manoj K. Mandal, Prakash Mathews, V. Ravindran, Satyajit Seth, *Drell-Yan, ZZ, $W+W-$ production in SM and ADD model to NLO+PS accuracy at the LHC,* (in preparation)

2. P. Artoisenet, P. de Aquino, F. Demartin, R. Frederix, S. Frixione, F. Maltoni, M. K. Mandal, P. Mathews, K. Mawatari, V. Ravindran, S. Seth, P. Torrielli, M. Zaro, *Higgs characterisation framework,* (in preparation)

3. Manoj K. Mandal, Prakash Mathews, V. Ravindran, Satyajit Seth, *Three photon production in SM at NLO+PS accuracy at the LHC,* (in preparation)

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, Januray 2013

Utkarsh Mishra

Research Summary:

During the year 2012-13, I have worked on quantum correlations in many particle systems and their dynamical properties in statistical models.

Quantum correlations in macroscopic systems is a key features of many quantum information processing and computational tasks and also important in measurement theory. We have proposed a Schrödinger cat-like state and have studied its coherence properties under environmental noise. We have taken particle loss and local depolarization as noise models. We found that the it is possible to choose the macroscopic sector of the Schrödinger cat state in such a way, that the resulting state is able to sustain finite amounts of particle loss and local decoherence as well as both. We have compared these results with other well-known cat-like states, and have found that the proposed state is more robust for the noise model considered.

In another work, at the interface of quantum information and statistical mechanics, we have investigated the validity of a statistical mechanical description of important quantum information quantities. We have performed this study in the anisotropic quantum Heisenberg model of spin-$\frac{1}{2}$ particles on one dimensional, ladder and two-dimensional lattices, with time-dependent magnetic field. In particular, we have investigated the ergodic properties of quantum correlations, belonging to the two broad paradigms in which the latter are defined . We found that the quantum correlations which lies within the entanglement-separability paradigm are ergodic. On the other hand, quantum correlations defined from an information-theoretic point of view showed a transition from an non-ergodic regime to an ergodic one with varying field and anisotropy of the system.

Publications:

1. Utkarsh Mishra, Aditi Sen(De), and Ujjwal Sen, *Quantum superposition in composite systems of microscopic and macroscopic parts resistant to particle loss and local decoherence* Phys. Rev. A 87, 052117, (2013).

2. Utkarsh Mishra, R. Prabhu, Aditi Sen (De), and Ujjwal Sen, *Tuning interaction strength leads to ergodic-nonergodic transition of quantum correlations in anisotropic Heisenberg spin model* Phys. Rev. A 87, 052318 , (2013).

Conference/Workshops Attended:

1. *International Conference on Quantum Information and Quantum Computing*, INDIA, January 2013. Presenteda poster on " Schrödinger cat resistant to particle loss and local decoherence".

Invited Lectures/Seminars:

1. *Symmetries and conservation laws in physics*, Scientific Workshops in Hindi, HRI, Allahabad, May 2012.

Avijit Misra

Research Summary:

In last one year with my PhD supervisor and collaborator I have worked on multipaty quantum correlation including its interface with relativistic physics and thermodynamics. We have studied that how the fidelity of remote state preparation changes when the receiever is in uniform motion or accelerating.

We have also shown that quantum discord can be expressed as a difference of change in the entanglement across various partitions of a purified state before and after the measurement. Using this new relation we have studied the time rate of change of quantum discord when the system evolves under a general non-local hamiltonian. The correlating capability of a non local hamiltonian is analyzed. We are trying to find what is the optimal way to generate quantum correlation starting from a zero discord state.

In classical information theory variation of information quantifies how much difference is there in two given clusters of a particular data set. We have suggested a quantum analog of variation of information and found some connection with multiparty quantum correlation.

We prove that the non-predictive information for driven quantum system is lower bounded by the change in the quantum correlation and upper bounded by the entropy production in the system and the environment. We argue that for a system to have more predictive information, it must retain the quantum correlation. Furthermore, we show that the discrepancy between the global and the local work extraction is directly related to the non-predictive information. This shows that at a fundamental level if a system has to be energetically efficient, it must minimise the loss of quantum correlation.

Preprints:

1. Arun Kumar Pati, Avijit Misra, *Predictive Information for Driven Quantum System,* (in preparation).

Conference/Workshops Attended:

1. *International Conference on Quantum Information and Quantum Computing*, India, January, 2013.

Other Activities:

1. Contributed to Talent Search Examination, Physics, organized by HRI for secondary and higher secondary level , November, 2012.

Asutosh Kumar

Research Summary:

Quantum systems manifest peculiar properties which are beyond the classical or everyday-life experiences. Entanglement is a fundamental concept in quantum mechanics and a useful resource for various tasks, like teleportation, dense coding, generating device-independent secret keys, and quantum state sharing among several parties. These applications have compelled researchers to look beyond the "spooky" aspects of entanglement in quantum systems, and to study its nature and amount in multiparty quantum states aimed at uncovering their further uses. In the previous academic year, I have studied the basics of quantum information, and am working on the *entanglement in multiqubit generalized "W-states"*.

Sourav Mitra

Research Summary:

Research presented in this report follows mainly two aspects of cosmological reionization: (1) semi-analytical modelling of cosmological reionization and comparison with recent observations and (2) CMB bounds on neutrino mass from reionization. A brief summary of my current research works is discussed in the following sections.

Reionization is a process whereby hydrogen (and helium) in the Universe is ionized by the radiation from first luminous sources. In the framework of the hot big bang model, the baryonic matter in the Universe is expected to become almost neutral after the recombination epoch at $z \sim 1100$. Given the fact (known from observations of quasar absorption spectra) that the Universe is highly ionized at $z < 6$, it is crucial to understand as to when and how did the luminous sources reionize the Universe. In the past few years, the understanding of reionization process has become increasingly sophisticated in both the observational and theoretical communities, thanks to the availability of good quality data related to reionization. However, recent studies suggest that reionization process is too complex to be described as a sudden process, in fact observations suggest that the reionization occurred somewhere between $z \sim 6 - 15$. Furthermore, the physical processes relevant to reionization are so complex that neither the analytical nor the numerical simulations alone can capture the overall picture. That's why, it is often studied using semi-analytical models of reionization, with limited computational resources. Using our semi-analytical model of reionization, we study the observational constraints on reionization via a principal component analysis (PCA). The advantage of this approach is that it provides constraints on reionization in a model–independent manner.

One of the most crucial issues regarding the evolution of intergalactic medium (IGM) and cosmic reionization is the escape fraction, $f_{\rm esc}$, of ionizing photons from high-redshift galaxies. This parameter remains poorly constrained in spite of many theoretical and observational attempts made in past few years. We propose a novel, semi-empirical approach based on a simultaneous match of the most recently determined Luminosity Functions (LF) of galaxies in the redshift range $6 \leq z \leq 10$ with reionization models constrained by a large variety of experimental data. From this procedure we obtain the evolution of the best-fit values of $f_{\rm esc}$ along with their 2-σ limits. We find that, averaged over the galaxy population, (i) the

escape fraction increases from $f_{\rm esc} = 0.068^{+0.054}_{-0.047}$ at $z = 6$ to $f_{\rm esc} = 0.179^{+0.331}_{-0.132}$ at $z = 8$; (ii) at $z = 10$ we can only put a lower limit of $f_{\rm esc} > 0.146$ (*Mitra, Ferrara & Choudhury 2012).* Thus, although errors are large, there is an indication of a 2.6 times increase of the average escape fraction from $z = 6$ to $z = 8$.

Using our semi-analytical reionization model, we also try to find the CMB bounds on neutrino masses as allowed by the datasets related to reionization. Neutrinos with non-zero mass can have an intense impression on the evolution of our Universe. Rigorous cosmological observations on cosmic microwave background (CMB) anisotropies and the large-scale structures of galaxies thus can be used to put a stronger constraint on the neutrino masses than that achieved from current laboratory experiments . Seven years of Wilkinson Microwave Anisotropy Probe (WMAP) data presents the upper bound on the sum of neutrino masses as $\sum m_\nu < 1.3$ eV at 95% confidence limits (CL), assuming a *sudden* reionization scenario depicted by a single parameter. Another feasible effect that could put an impact on the CMB bounds for neutrino masses is the detailing of reionization scenario. So, we also try to investigate the possible effects on neutrino mass bound by considering our data-constrained reionization model based on *Choudhury & Ferrara (2005, 2006)* and *Mitra, Choudhury, & Ferrara (2011,2012)* and we find that, a more strict constraint on the neutrino masses can be achieved using this model.

Publications:

1. Mitra, Sourav; Ferrara, Andrea; Choudhury, T. Roy, *The escape fraction of ionizing photons from high-redshift galaxies from data-constrained reionization models*, MNRAS Letter **428**, 1, (2013)

Preprints:

1. Mitra, Sourav; Choudhury, T. Roy; Ferrara, Andrea, *Neutrino mass from data-constrained reionization models*, (in preparation)

Conference/Workshops Attended:

1. *Workshop on Large Scale Structure*, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, July. 30 – Aug. 2, 2012.
2. *Summer School on Cosmology*, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, July. 16 – July. 27, 2012.

Visits to other Institutes:

1. National Centre for Radio Astrophysics (NCRA), Pune, India, Aug 23 – Dec 31, 2012.
2. The Astronomical Observatory of Brera (OAB), Merate, Italy, July 12 – July 14, 2012.
3. Max-Planck-Institute for Astrophysics (MPA), Garching, Germany, July 11 – July 12, 2012.
4. Leibniz Institute for Astrophysics Potsdam (AIP), Potsdam, Germany, July 08 – July 10, 2012.

Invited Lectures/Seminars:

1. *Observational constraints on reionization scenario*, National Centre for Radio Astrophysics (NCRA), Pune, India, Dec, 2012.
2. *Reionization constraints using principal component analysis*, Summer School on Cosmology, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, July, 2012.
3. *Reionization constraints using principal component analysis*, The Astronomical Observatory of Brera (OAB), Merate, Italy, July, 2012.
4. *Reionization constraints using principal component analysis*, Max-Planck-Institute for Astrophysics (MPA), Garching, Germany, July, 2012.
5. *Reionization constraints using principal component analysis*, Leibniz Institute for Astrophysics Potsdam (AIP), Potsdam, Germany, July, 2012.

Swapnamay Mondal

Research Summary:

During this this period I have been working on mainly two projects, described as follows-
A. One of the most intriguing features of string theory is the web of various dualities .We aim to use this feature to count microstates of certain supersymmetric Black Holes. We exploit the followiong facts - 1. certain supersymmetric black holes and certain D-brane systems can be thought respectively as strong and weak gravity descriptions of same physical systems. 2. in a supersymmetric theory, certain quantities do not change as we vary the strength of interaction.
Thus the problem of counting Black Hole microstates can be mapped to roughly the problem of counting possible number of D-brane configurations(with a given charge and supersymmetry), more precisely , counting supersymmetric ground states in the low energy effective field theory describing the dual D brane system . This work is going on in the supervision of my supervisor prof. Ashoke Sen. Abhishek Chowdhury and Richard Garavuso are also collaborating with me in this work. .

B . The weak coupling dynamics of YM gauge theory is captured by some effective unitary matrix model, the fundamental variables being the eigenvalues of the holonomy matrix along the thermal circle. For finite temperature $U(N)$ gauge theories on $S^3 \otimes S^1$ (S^1 stands for the thermal circle), an exact solution of these models for any finite N was found in $arXiv : 0711.0133v2$ Apart from obtaining important results relevant for AdS/CFT duality , it was observed that one can regard eigenvalue density and density of Young tableaux , as canonically conjugate varibales and in large N (i.e classical) limit, can think of the system as a collection of non-interacting Fermions. Large N saddle points of the gauge theory effective action (which corresponds to thermal AdS, small Black Holes and big Black Holes) , can each be thought in terms of particular configurations of free fermionic phase space. We would like to have a deeper understanding of this aparrently strange connection.
For this , we note that there is connection between Chern Simons theories and Fermions, which is relatively better understood. So we wish to solve $U(N)$ Chern Simons theory on $S^2 \bigotimes S^1$ on parallel lines of $arXiv : 0711.0133v2$ and have a deeper understanding of the physical origin of the intriguing connection mentioned before.
This work is going on under the supervision of prof. Rajesh Gopakumar.

Conference/Workshops Attended:

1. *Advanced String School*,Puri, India, October 2012
2. *Indian String Meet*,Puri, India, December 2012

Other Activities:

1. I have worked as tutor of Classical Mechanics course taken during August-December 2012 semester by Prof. Rajesh Gopakumar .

Roji Pius

Research Summary:

In the last year with my supervisor Rajesh Gopakumar we compared the planar correlators in the Gaussian matrix model with corresponding genus zero correlators of the A-model topological string theory on 2 sphere. We found a simple relation between them which provides additional evidence for the duality between the two theories as proposed by Gopakumar. In addition to their value as a toy model of AdS/CFT, may also be significant in the canonical gauge-string duality between $N = 4$ super Yang-Mills theory and the string theory on $AdS5 \times S5$. The localization arguments of Vasilev Pestun have shown how the half BPS Wilson loops in the gauge theory reduce to a Gaussian matrix integral. Given this duality, we hope that there is a corresponding localization of the $AdS5 \times S5$ string theory in the half BPS sector which reduces the string sigma model to the A-model topological string theory on 2 sphere. To verify this we are trying to do the localization of string sigma model for the superstring in $AdS5 \times S5$ derived using the pure spinor formalism.

With Ashoke Sen we are investigating the importance of generalized orientifold limits of F-theory in the geometric engineering of $SU(5)$ Grand Unified Theories in F-theory. In another line of investigation again with Ashoke Sen we are trying to explore S-dulaity to compute the physical quantities at finite coupling of superstring theory. Recently Sen computed the mass of the stable non-BPS state in SO(32) heterotic/type I string theory via interpolation between strong and weak coupling. We are trying to explore how the result generalizes when we compactify one or more directions on circles.

Publications:

1. Rajesh Gopakumar and Roji Pius, *Correlators in the Simplest Gauge-String Duality,* JHEP **1303**, 175, (2013)

Conference/Workshops Attended:

1. *Discussion meeting on string theory* , ICTS, Bangalore, India, June, 2012.
2. *Advanced String Theory School*, Puri, India, October, 2012.
3. *From Strings to LHC - III*, Puri, India, December, 2012.

4. *Indian Strings meeting 2012*, Puri, India, December, 2012.

5. *Spring School on Superstring Theory and Related Topics*, Italy, ICTP, March, 2013.

Visits to other Institutes:

1. ICTS, Bangalore, India, June, 2012.

2. ICTP, Trieste, Italy, March, 2013.

Sabyasachi Tarat

Research Summary:

I am investigating the properties of superconductors in lattice systems, through numerical simulations of simplified model Hamiltonians. These take into account an attractive interaction U between up and down spin electrons (without worrying about where they originate from), homogeneous disorder through a random potential at each site and/or the presence of magnetic/non-magnetic impurities. We use a travelling cluster approach which enables us to treat large lattice systems of $O(40 \times 40)$, giving us unprecedented access to spatial correlations and thermal fluctuations in the systems. Our work so far can be broadly divided into three parts, as detailed below.

1) BCS-BEC Crossover: We studied the 'clean' problem (without disorder) and its properties with varying U. This system undergoes a crossover from a weak-coupling standard 'BCS' superconductor to a strong coupling 'BEC' superfluid consisting of tightly bound local pairs that act like bosons. Important indicators of this include a non-monotonic transition temperature T_c with U, and a prominent pseudo-gapped phase at intermediate coupling above T_c. We constructed a phase diagram detailing these phases and compared various indicators with other established methods, thus clarifying the strengths and weaknesses of our method. This analysis lays the groundwork for the study of more complicated problems, where fewer alternative techniques are available.

2) Disorder induced SIT: A random potential field in a superconductor can suppress superconductivity and finally lead to an insulating state as its strength is increased. We studied this superconductor insulator transition (SIT) at 'weak' coupling ($U \sim 2$). Our method enables us to clarify the thermal physics of the system at various disorder values by investigating local indicators as well as global properties like transport and spectral functions. We compare our results with extensive existing experimental data and suggest directions for further investigation.

3)(a) Magnetic impurities in superconductors: Magnetic impurities break time reversal invariance, and hence can have a very prominent effect on superconductivity even at low concentration, giving rise to the famous 'gapless' phase, where superconductivity is intact even though the system is gapless. We are studying the effect of frozen magnetic impurities in superconductors at varying concentrations and impurity strengths. Our method allows us to go far beyond the Abrikosov-Gorkov regime and

shed light on the thermal physics. (b) Magnetic superconductors : We are also studying superconductors in a lattice of magnetic spins where we allow thermal annealing of the spins as well. We have found coexistence regimes where superconductivity coexists with magnetic order. Near half filling, the magnetic order is antiferromagnetic, whereas we find ferromagnetism at low filling ~ 0.3. Variational calculations indicate the presence of magnetic order of intermediate periodicity at intermediate filling ($n \sim 0.4-0.7$). I am currently studying this intermediate regime and trying to link our results with relevant experimental data.

Preprints:

1. S. Tarat and Pinaki Majumdar, *The interplay of amplitude and phase fluctuations across the BCS-BEC crossover in attractive Fermi systems* (in preparation)

2. S. Tarat and Pinaki Majumdar, *Charge Dynamics and Spectral Features Across the Disorder Driven Superconductor-Insulator Transition,* (in preparation)

3. S. Tarat and Pinaki Majumdar, *Tunnelling Spectroscopy Across the Thermal Transition in a Strongly Disordered Superconductor,* (in preparation)

Akansha Singh

Research Summary:

In this academic year my main work was on theoretical studies on graphite supported silver cluster[1].

Supported metals are among the most important catalysts and their catalytic activity can be altered when used as small metal clusters. Here we present the adsorption of small Agn (n=1,7) clusters on graphite surface, which has been studied using first-principles density functional theory methods. All electronic calculations were performed using a plane wave based density functional theory code Vienna ab initio simulation package (VASP) with periodic boundary conditions. Exchange and correlation functionals were implemented within local density approximation (LDA), since generalized gradient approximation (GGA) is unable to generate interlayer binding of graphite[2]. The graphite surface has been modeled as a 3-layer graphite slab, since the effect of other layers was negligible. Out of which only two of them were relaxed during optimization. All initial structures were obtained by rotating gas phase silver clusters over the graphite surface.

A single silver atom is found to prefer the beta-site on graphite surface, but the insignificant energy differences among binding sites indicate its high mobility over the surface, which is in agreement with the previous experiments[3],[4]. Silver clusters having odd number of atoms have larger adsorption energy on the graphite surface in comparison to those having even number of atoms. The odd-sized clusters lose their unpaired spin after deposition. Silver clusters retain their gas phase structures even after deposition, which indicates the stronger Ag-Ag binding within the cluster than Ag-C binding with the surface. Up to size n=5, Ag clusters prefer to stay perpendicular to surface, so that the Pauli repulsion[5] between cluster and surface can be minimized. For clusters of size more than n=5, binding energy of cluster and surface is able to overcome this repulsion, and the lowest energy structures have the clusters parallel to the surface. Silver clusters of all sizes shows a partial charge transfer to graphite surface, the transfer being slightly higher for odd-sizes. Hence, the graphite supported odd-sized silver clusters are more stable in comparison to even-sized ones, since they transfer their unpaired electron to the graphite surface. At smaller sizes structure of the absorbed cluster is more governed by the repulsive interactions than by the binding to the surface.

Reference:

1. Z. Xu et al., Nature, 372 **(1994)** 346.
2. Newton Ooi, Asit Rairkar, James B. Adams, Carbon, 44 **(2006)** 231.
3. Eric Ganz, Klaus Sattler, John Clarke, Surface Science, 219 **(1989)** 33.
4. Gebhu F Ndlovu et al., Nanoscale Research Letters, 7 **(2012)** 173.
5. Anna M Ferrari et al., Phys. Chem. Chem. Phys., 1 **(1999)** 4655.

Conference/Workshops Attended:

1. International Symposium on Science of Clusters, Nanoparticles and Nanoscale Materials (SOCNAM-2013), CURAJ, Jaipur, March 2013
2. 4^{th} Interdisciplinary Symposium on Materials Chemistry, BARC, Mumbai, December 2012
3. An Advanced School on Modelling Complex Oxides, S N Bose, Kolkata, April 2012

Visits to other Institutes:

1. BARC Mumubai, August 2012

Nyayabanta Swain

Research Summary:

Geometrical frustration in strongly-correlated systems results in novel ground states. Also the thermal physics in these systems are non-trivial. In that respect we have done works on the pyrochlore lattice and its 2D analog, the checkerboard lattice. To study the Mott-physics in both these systems we restrict ourselves to half-filling. But these systems have some peculiar properties at half filling (the Fermi level just touches a flat band) which invalidate standard perturbation calculations and thus makes theoretical investigations extremely difficult. This in turn poses a challenging theoretical problem to study the Mott-physics in these frustrated systems. Using Monte-Carlo simulation based on a new method of auxiliary fields in real space, we have studied the metal-insulator transition, magnetic correlations, electronic properties and their thermal evolution in the checkerboard lattice. The standard Heisenberg anti-ferromagnetic model on both the checkerboard and pyrochlore lattice have also been studied for insights at sufficiently large interaction. Our focus is on the Iridium based pyrochlores on which there are ample experimental results but hardly any conclusive theoretical work.

We are also studying the interplay of Mott-Physics and superconductivity in another frustrated system, the triangular lattice. Both the zero-temperature and finite temperature magnetic and superconducting correlations and the electronic properties are being studied in this system.

Both these works are being done with Prof. Pinaki Majumdar.

Conference/Workshops Attended:

1. *ATHENA-2012, An Advanced School on Modelling Complex Oxides*, S.N. Bose National Center for Basic Sciences, Kolkata, India. April, 2012

Other Activities:

1. Teaching Assistant for the Condensed Matter Physics-I (CMP-1) course during Aug-Dec, 2012.

Manabendra Nath Bera

Research Summary:

During the academic year 2012-13, I have worked, as a part of the QIC group, in several topics which can be divided in three parts.

First, we have continued and enriched our research work, which has been started in the previous academic year, on the multipartite entanglement behavior in the context of quantum phase transition (QPT) in a spin-$1/2$ XX chain with three-spin interaction. We have demonstrated that the multipartite entanglement measure, called generalized geometric measure (GGM), is a better and reliable indicator of the QPT of this spin system than the bipartite entanglement measures, such as concurrence. We have also thoroughly investigated the properties of both bipartite and multipartite quantum entanglement before and after the quantum phase transition.

Second, we have studied the time-energy uncertainty in terms of the geometry of quantum state space. We found a direct connection and role of multipartite quantum entanglement in the time evolution of the multipartite quantum state. We establish a relation between the geometric time-energy uncertainty and multipartite entanglement. In particular, we show that the time-energy uncertainty relation is bounded below by the geometric measure of multipartite entanglement for an arbitrary quantum evolution of any multipartite system. The product of the time-averaged speed of the quantum evolution and the time interval of the evolution is bounded below by the multipartite entanglement of the target state. This relation holds for pure as well as for mixed states. We have studied several physical systems for which the bound reaches close to saturation and also investigated this relation in the case of Grover search algorithm.

Third, we have investigated the quantum part of the variance of a quantum observable, also called the Anandan quantum fluctuation (AQF), for composite quantum states. The AQF is, in fact, responsible for the evolution of a general (pure or mixed) quantum state by an unitary operator and also for the intrinsic fluctuation introduced to a quantum state in the process of observing a Hermitian observable. We show that for a bipartite quantum state the local AQF is bounded below by the amount of quantum correlation present in the system, measured by quantum discord. So, for a composite system, minimum disturbance or quantum fluctuation introduced depends quantitatively on the quantum correlation present. We derive the Schödinger-Robertson quantum uncertainty relation for local observable in terms of local AQF in the presence of quantum correlation

and show that this relation can give a tighter bound from below. We have investigated several implications of the local quantum uncertainty relation in metrology in the presence quantum correlation.

Publications:

1. Manabendra N. Bera, R. Prabhu, Aditi Sen (De) and Ujjwal Sen, *Characterization of tripartite quantum states with vanishing monogamy score,* Phys. Rev. A **86**, 012319, (2012).

Preprints:

1. Manabendra N. Bera, R. Prabhu, Aditi Sen (De) and Ujjwal Sen, *Multisite Entanglement acts as a Better Indicator of Quantum Phase Transitions in Spin Models with Three-spin Interactions,* arXiv:1209.1523 [quant-ph].

2. Manabendra Nath Bera, R. Prabhu, Arun Kumar Pati, Aditi Sen (De) and Ujjwal Sen, *Limit on Time-Energy Uncertainty with Multipartite Entanglement,* arXiv:1303.0706 [quant-ph].

3. Manabendra Nath Bera, R. Prabhu, Arun Kumar Pati, Aditi Sen (De) and Ujjwal Sen, *Quantum Uncertainty, Correlation and Dynamics for Mixed Quantum States,* (in preparation).

Conference/Workshops Attended:

1. *International Conference on Quantum Information and Quantum Computing (ICQIQC)*, IISc Bangalore, India, January 2013.

Visits to other Institutes:

1. Indian Institute of Technology, Kanpur, India, September 2012.

Sourav Bhattacharya

Research Summary:

I have worked on classical black hole no hair theorems, construction of mass functions in de Sitter black hole spacetimes, and particle motion in such spacetimes. Apart from this, I am now working on some aspects of interacting quantum field theory in Riemann-Cartan spacetimes. I have plan to study the motion of massless quantum fields in certain de Sitter black hole spacetimes.

Publications:

1. Sourav Bhattacharya, Amitabha Lahiri, *Massive spin-2 and spin-1/2 no hair theorems for stationary axisymmetric black holes,* Phys. Rev. D **86**, 084038, (2012)

Preprints:

1. Sourav Bhattacharya, Amitabha Lahiri, *Mass function and particle creation in Schwarzschild-de Sitter spacetime,* arXiv:1301.4532.

2. Tapas K Das, Sankhasubhra Nag, Swathi Hegde, Sourav Bhattacharya, Ishita Maity, Bozena Czerny, Paramita Barai, Paul J Wiita, Vladimir Karas, Tapan Naskar, *Behaviour of low angular momentum relativistic accretion close to the event horizon,* arXiv:1211.6952.

3. Sourav Bhattacharya *A note on black hole no hair theorems for massive forms and spin-$\frac{1}{2}$ fields,* (in preparation).

Conference/Workshops Attended:

1. *27th IAGRG Meeting*, Sreenagar, Uttarakhand, INDIA, March, 2013.

Anindya Biswas

Research Summary:

I have worked mainly in the field of quantum information and its interface with many-body physics in the academic year "2012-2013". We have studied multipartite entanglement in various spin models in one and two dimensions. We have used numerical techniques like the Lanczos algorithm to diagonalize the many-body Hamiltonians of the spin systems. We have found that multipartite entanglement acts as a better indicator than bipartite entanglement in detecting quantum phase transitions in the frustrated quantum systems.

Entanglement and other information theoretic quantum correlation measures like quantum discord and quantum work-deficit have been established to be valuable resources in various quantum information protocols. There have, however, been indications that this may not be the entire picture, and that there may be important resources that are employed by nonclassical phenomena in the domain of shared quantum systems. We have conceptualized and proposed a measure of shared quantum systems, which we have called shared purity, and which we have shown to be independent of quantum correlations, qualitatively and quantitatively. The concept is based on the maximal fidelity of the shared quantum state to certain sets of pure quantum states. We prove that shared purity is qualitatively monogamous, in the sense that a maximal shared purity between two parties excludes any shared purity of these parties with a third party. We apply the quantity to investigate the quantum XY spin models, and observe that it can faithfully detect the quantum phase transition present in these models. We perform a finite-size scaling analysis and find the scaling exponent for this quantity.

I have also studied the thermodynamic properties of ultracold Bose gases using the correlated potential harmonic expansion method (CPHEM). We define the transition exponent, which characterizes the nature of a thermodynamic quantity like specific heat at the transition point of a quasi phase transition, and evaluate them by careful numerical calculations, very near the transition temperature. These exponents are found to be independent of the size of the system. They are also the same for interacting and non-interacting bosons. These demonstrate the universality property of the transition exponents.

I have investigated the characteristics of Shannon information entropy for ultracold trapped interacting bosons using CPHEM. We reformulate the

one-body Shannon information entropy in terms of one-body probability density. We approach the minimum limit of the entropy uncertainty relation(EUR) making particle number very small in our numerical work. We examine the strong correlation effect in the calculation of information entropy. Comparison with the mean-field result shows that the correlated basis function is indeed required to characterize the realistic features of information entropies.

Publications:

1. Sanchari Goswami, Tapan Kumar Das, **Anindya Biswas**, *Thermodynamic Properties of Ultracold Bose Gas: Transition Exponents and Universality,* Journal of Low Temperature Physics, online first article, February, (2013)

Preprints:

1. **Anindya Biswas**, Aditi Sen De, Ujjwal Sen, *Shared Purity of Multipartite Quantum States,* arXiv:1306.0669 [quant-ph]

2. Sudip Kumar Haldar, Barnali Chakrabarti, Tapan Kumar Das, **Anindya Biswas**, *Correlated many-body calculation to study characteristics of Shannon information entropy for ultracold trapped interacting bosons,* arXiv:1303.7045 [cond-mat.quant-gas]

3. **Anindya Biswas**, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Genuine Multipartite Entanglement Trends in Gapless-gapped Transitions of Quantum Spin Systems,* arXiv:1211.3241 [quant-ph]

Visits to other Institutes:

1. University of Calcutta, Kolkata, India, May 2012,

2. University of Calcutta, Kolkata, India, June 2012,

3. University of Calcutta, Kolkata, India, November 2012.

Other Activities:

1. Helped in conducting the Talent Search Examinations (physics part) for students of classes IX-X and classes XI-XII of schools in Allahabad, 2012-2013.

2. Delivered a talk on *Patterns of multisite entanglement in quantum many-body systems*, HRI, October, 2012.

3. Delivered a talk on *Bose-Einstein Condensation*, QIC group at HRI, June, 2012.

Richard Scott Garavuso

Research Summary:

I have been working on two projects:

1. The first project, a collaboration with Prof. Eric Sharpe of Virginia Tech, is nearly complete.

   Tentative title: Analogues of Mathai-Quillen forms in sheaf cohomology and applications to topological field theory

   Abstract: In this note we construct a deformation of the usual Mathai-Quillen form, resulting in a holomorphic object interpreted in terms of sheaf cohomology, and analyze its mathematical properties. This deformation arises physically in the A/2 model pseudo-topological field theory, and we briefly comment on its physical origin and role.

2. The second project is a collaboration with Prof. Ashoke Sen, graduate student Abhishek Chowdhury, and graduate student Swapno Mondal. In this project, we consider the spectrum of elementary Type II strings compactified on T^6. U-duality converts BPS states into bound states of Dirichlet branes which wrap around intersecting cycles of T^6. We assume that T^6 is along the 4-5-6-7-8-9 plane. We further assume that there is a stack $s^{(1)}$ of m_1 D_2-branes wrapping cycles in the 4-5 plane, a stack $s^{(2)}$ of m_2 D_2-branes wrapping cycles in the 6-7 plane, a stack $s^{(3)}$ of m_3 D_2-branes wrapping cycles in the 8-9 plane, and a stack $s^{(4)}$ of m_4 D_6-branes wrapping cycles in the 4-5-6-7-8-9 plane.

Preprints:

1. R.S. Garavuso and E. Sharpe, *Analogues of Mathai-Quillen forms in sheaf cohomology and applications to topological field theory,* (in preparation).

2. R.S. Garavuso, A. Chowdhury, S. Mondal, A. Sen., *D-brane project described above,* (in preparation).

Conference/Workshops Attended:

1. *Advanced String Theory School IV, Institute of Physics, Bhubaneswar*, India, October, 2012.

2. *From Strings to LHC- III*, India, December 2012.

3. *ISM2012*, India, December 2012.

Invited Lectures/Seminars:

1. *Deformed Mathai-Quillen forms in A-twisted (0,2) Landau-Ginzburg models*, Journal Club Seminar, Harish-Chandra Research Institute, India, April 2013.

Yoshinori Homma

Research Summary:

During the academic year 2012-2013, I studied the dynamics of M-theory branes and related mathematical physics.

In collaboration with Masazumi Honda (KEK, Japan), I computed the superconformal indices of the ABJM theories and the BLG theories for various values of the rank of the gauge group and the Chern-Simons level. By comparing the results, we confirmed the isomorphisms between several M2-brane theories which has been expected from the classical moduli space analysis.

I also developed the technique of calculating the Gromov-Witten invariants. Along with Masahide Manabe (HRI), I studied quantum Kahler moduli space of Calabi-Yau fourfolds. In particular, we conjectured the explicit form of the quantum-corrected Kahler potential. We computed the genus zero Gromov-Witten invariants for several examples and test our conjecture by comparing the results with mirror symmetry predictions.

Publications:

1. Masazumi Honda, Masanori Hanada, Yoshinori Honma, Jun Nishimura, Shotaro Shiba and Yutaka Yoshida, *Numerical studies of the ABJM theory for arbitrary N at arbitrary coupling constant,* Int. J. Mod. Phys. Conf. Ser **21**, 203, (2013)

2. Yoshinori Honma and Masahide Manabe, *Exact Kahler Potential for Calabi-Yau Fourfolds,* JHEP **1305**, 102, (2013)

3. Masazumi Honda, Masanori Hanada, Yoshinori Honma, Jun Nishimura, Shotaro Shiba and Yutaka Yoshida, *Monte Carlo studies of 3d N=6 SCFT via localization method,* PoS **LATTICE2012**, 233, (2012)

4. Masazumi Honda and Yoshinori Honma, *3d superconformal indices and isomorphisms of M2-brane theories,* JHEP **1301**, 159, (2013)

Conference/Workshops Attended:

1. *Indian Strings Meeting 2012*, India, December 2012.

2. *KEK Theory Workshop 2013*, Japan, March 2013.

Visits to other Institutes:

1. KEK Theory Center, Ibaraki, Japan, March 2013.

Invited Lectures/Seminars:

1. *2d Gauge Theories and Calabi-Yau manifolds*, Poster presentation at "KEK Theory Workshop 2013", KEK, Ibaraki, Japan, March 2013.

Masahide Manabe

Research Summary:

Topological string theory provides a framework to understand various topics in mathematical physics such as supersymmetric gauge theory, matrix model, enumerative geometry, knot theory etc.
The two dimensional $\mathcal{N} = (2, 2)$ gauged linear sigma model (GLSM) is an efficient tool to describe topological strings, and recently the GLSM partition function on two sphere was exactly computed. Furthermore for Calabi-Yau manifolds, it was proposed that this exact result gives us the exact Kähler potential on the quantum Kähler moduli space of Calabi-Yau manifold. From this quantum-corrected Kähler potential one can also extract the genus zero Gromov-Witten invariants. Based on these results, with Y. Honma, we conjectured a formula of the exact Kähler potential for Calabi-Yau fourfolds. We also extracted the Gromov-Witten invariants for some fourfold examples, and checked the consistency with mirror symmetry predictions.

Publications:

1. Y. Honma and M. Manabe, *Exact Kahler Potential for Calabi-Yau Fourfolds,* JHEP **1305**, 102 (2013).

Conference/Workshops Attended:

1. *Indian Strings Meeting 2012*, India, December, 2012.

Kenji Nishiwaki

Research Summary:

During the period April 2012–March 2013, I had proceed with the topics of collider physics and flavor physics in extra dimensions with my collaborators. We can pursue lots of issues that are unexplained in particle physics with the help of geometric structure interwoven in the extra spatial dimension(s). Recently, in view of the importance of the LHC, I also give priority to collider physics issues with detailed numerical calculations that include sophisticated simulations with the help of publicly available software.

Publications:

1. AseshKrishna Datta, Kenji Nishiwaki, and Saurabh Niyogi,
"Non-minimal Universal Extra Dimensions: The Strongly Interacting Sector at the Large Hadron Collider" *JHEP* **1211**, 154, (2012).

2. Yukihiro Fujimoto, Tomoaki Nagasawa, Kenji Nishiwaki, and Makoto Sakamoto,
"Quark mass hierarchy and mixing via geometry of extra dimension with point interactions", *Prog. Theor. Exp. Phys.* **023B07**, (2013).

3. Yukihiro Fujimoto, Tatsuo Kobayashi, Takashi Miura, Kenji Nishiwaki, and Makoto Sakamoto,
"Shifted orbifold models with magnetic flux", *Phys. Rev.* **D87**, 086001, (2013).

Preprints:

1. Yukihiro Fujimoto, Kenji Nishiwaki, and Makoto Sakamoto,
"CP phase from twisted Higgs VEV in extra dimension", arXiv:1301.7253 [hep-ph].

Conference/Workshops Attended:

1. *Progress in particle physics*, Japan, July 2012.

2. *Higgs meeting*, Japan, July 2012.

3. *Collaboration meeting*, India, November 2012.

4. *String to LHC III*, India, December 2012.

5. *XX DAE-BRNS HEP Symposium*, India, January 2013.

6. *HIGGSTOP-2013*, India, February 2013.

7. *SANGAM meeting*, India, March 2013.

Visits to other Institutes:

1. Kobe University, Kobe, Japan, July–August 2012.

2. Osaka University, Osaka, Japan, July 2012.

3. Kyoto University, Kyoto, Japan, July 2012.

4. Toyama University, Toyama, Japan, July 2012.

5. Saitama University, Saitama, Japan, August 2012.

6. Niigata University, Niigata, Japan, August 2012.

Invited Lectures/Seminars:

1. *Origin of quark profiles is junctions in extra dimension*, Seminar talk, Harich-Chandra Research Institute, Allahabad, India, June 2012.

2. *Non-minimal Universal Extra Dimension: The QCD interactions at the LHC*, Short talk at the conference "Progress in particle physics 2012", YITP, Kyoto, Japan, July 2012.

3. *Non-minimal Universal Extra Dimension: the QCD interacting sector at the LHC*, Seminar talk, Toyama University, Toyama, Japan, July 2012.

4. *Non-minimal Universal Extra Dimension: the strongly interacting sector at the LHC*, Seminar talk, Osaka University, Osaka, Japan, July 2012.

5. *Non-minimal Universal Extra Dimension: the strongly interacting sector at the LHC*, Seminar talk, Saitama University, Saitama, Japan, August 2012.

6. *Non-minimal Universal Extra Dimension: the strongly interacting sector at the LHC*, Seminar talk, Niigata University, Niigata, Japan, August 2012.

7. *Non-minimal Universal Extra Dimension: the strongly interacting sector at the LHC*, Seminar talk, Kobe University, Kobe, Japan, August 2012.

8. *Signals of Flat Universal Extra Dimensions*, Invited review talk at collaboration meeting, Harish-Chandra Research Institute, Allahabad, India, November 2012.

9. *Quark mass hierarchy and mixing via geometry of extra dimensions*, Short talk, "String to LHC III", Pune, India, December 2012.

10. *Quark mass hierarchy and mixing via geometry of extra dimensions with point interactions*, Short talk, XX DAE-BRNS HEP Symposium, Visva-Bharati, Bolpur, India, 15 January 2013.

Satoshi Ohya

Research Summary:

It has been long appreciated that supersymmetry and its generalizations are ubiquitous and play an important role in quantum mechanics with spectral degeneracy. In the academic year 2012-2013, I studied a single free spinless particle on quantum wire junctions (or quantum graphs) and found that parasupersymmetry, which is a generalization of supersymmetry to parastatistics (i.e. symmetry between bosons and parafermions), is generally hidden behind degenerate spectra even without parafermion degrees of freedom.

Publications:

1. Satoshi Ohya, *Parasupersymmetry in quantum graphs,* Annals Phys. **331**, 299-312, (2013)

2. Satoshi Ohya, *Path integral junctions,* J. Phys. **A45**, 255305, (2012)

Preprints:

1. Satoshi Ohya, *Parasupersymmetry in Quantum Graphs,* arXiv:1210.7801

Visits to other Institutes:

1. KEK, Tsukuba, Japan, December 2012,

2. Tokyo Metropolitan University, Hachioji, Japan, December 2012.

Invited Lectures/Seminars:

1. *Path Integral Junctions*, Seminar, KEK, Tsukuba, December 2012.

2. *Parasupersymmetry in Quantum Graphs*, Seminar, Tokyo Metropolitan University, Hachioji, December 2012.

Efunwande Osoba

Research Summary:

I am interested in broad questions at the intersection of particle physics, cosmology and astrophysics. I have done some work in neutrino physics and physics beyond the standard model. I will highlight below some of my personal interests as it relates to and extends work previously have done.

In the astroparticle sector, I have done some work studying the sterile neutrino production early universe. The framework of the low reheating temperature models to the heavy sterile neutrino. These sterile neutrinos are produced through active-sterile neutrino oscillations in the presence of a negligible lepton asymmetry. We show that these models relaxes cosmological bounds on the small mixing angles imposed by the standard cosmology. Since there is a very high reheating temperature in the standard cosmology, too many primordial sterile neutrino are being produced, and the way to alleviate constraints from the diffuse extragalactic background and nucleosynthesis is to have very small active-sterile mixing angles. The very small angles make observing sterile neutrinos in experiments, very difficult. In our work, the mixing angle could be larger by as much as a factor of two orders of magnitude. Since we have no experimental evidence before Big Bang Nucleosynthesis (BBN), it is a dubious exercise to use conditions from before BBN to constrain these mixing angles. Therefore, if the existence of the sterile neutrino is found, this could be proof positive for cosmology happening in a fashion different from the Standard lore.

My interest in cosmology had led me into research in baryogenesis. I and Raj Gandhi are interested in baryon asymmetry generation through thermal leptogenesis from the out of equilibrium decays of right handed neutrinos. We investigate models in which the CP asymmetry can generated by B/L number violation at one loop order through the interference of tree level decay of RH neutrinos and one loop mediated RH neutrinos decays. We have decided on an analytic approach, in which we investigate thermal leptogenesis in the strong washout regime. In this regime, it is sufficient to consider L-violating decays and inverse decays. While L-violating scattering processes do play a role, we can safely ignore their contributions in the strong-washout regime. Our task now is the calculate exactly the CP parameter epsilon and give an analytic estimate of the baryon asymmetry generated. This research is on going

I also have have some interest in neutrino models beyond the standard model physics. I had studied specifically sterile neutrinos in a model of two Higgs Doublets and an added Z_2 symmetry. Under this discrete symmetry, the Standard Model particles are even, while the singlet fermions or the inert sterile neutrinos and the additional Higgs doublet are odd. The model could explain a natural heavy Higgs boson. The additional scalar fields have been shown to offer corrections to the S and T parameters set by the electroweak precision tests. With these corrections, one can have a heavy Higgs boson, bigger than 200 GeV. The three added singlet fermions give the Standard Model neutrinos a mass through one loop effects. The lightest of the singlet fermions and a component of the additional Higgs doublet have been identified as dark matter through the thermal production in the early universe. I looked into mechanisms of non-thermal dark matter in this model.

My interest in beyond the standard model physics led me to study particle physics models with a fourth sequential generation. I have looked into natural models to explain the hierarchy between the neutrino masses of the standard model neutrinos and the fourth generation neutrinos. I proposed a model with four generations and three Higgs doublets and three extra singlet fermions. I show how the standard model neutrinos acquire tiny masses through loop effects, and the fourth generation neutrinos acquire natural heavy Dirac masses. The model also has some dark matter candidates. The scalar sector introduces new sources of CP violation in the model, which is quite interesting given the new results from LHC B that seemed to hints to extra sources of CP violation in the standard model. Recent LHC recents have given some constraints on extra generation models. However, there are some interesting ways of voiding the tension in these type models. I specifically explore in the ways enlarging the scalar sector or adding singlet fermions can increase help ease collider constraints in fourth generation and fifth generation models.

Motivated by hints for eV scale sterile neutrinos from the Miniboone experiment, I, in collaboration with Sandhya Choubey, have researched GUT scale models in which sterile neutrinos could have light masses. This led us into SO(10) GUT models imposed with a discrete symmetry, such as S_4. With a judicious choice of vev alignments, we are able to have specific forms of the neutrino mass matrix that allow for eV scale sterile neutrino masses. In addition, we were able to show that the model yields the right spectrum of the quark and lepton masses, quark mixing angles at the GUT scale.

Publications:

1. E. Osoba, G. B. Gelmini, and S. Palomares-Ruiz, *Inert-Sterile Neutrino: Cold or Warm Dark Matter Candidate,* Phys. Rev. D **81**, 063529 (2010)

2. G. Gelmini, E. Osoba, S. Palomares-Ruiz and S. Pascoli, *MeV sterile neutrinos in low reheating temperature cosmological scenarios,*, JCAP **0810**, 029 (2008)

Preprints:

1. Efunwande Osoba, *Fourth Generations with an Inert Doublet Higgs,* arXiv:1206.6912

2. Sandya Choubey, Efunwande Osoba, *Light Sterile Neutrinos in SO(10) GUT models* in preparation.

Conference/Workshops Attended:

1. *Workshop on the Higgs*, India, September 2012

2. *Sangam /@ HRI Instructional Workshop*, India, Feburary 2013

Visits to other Institutes:

1. University of California, Los Angeles USA, June 2012,

2. University of California, Los Angeles USA, May 2013,

Invited Lectures/Seminars:

1. *Fourth Generations with an Inert Doublet Higgs*, University of California, Los Angeles, June 2012.

Andreas Nyffeler

Research Summary:

My field of research is phenomenological particle physics. I work on precision tests of the Standard Model, mainly the muon $g-2$, and on New Physics models in the TeV region. I am particularly interested in the analysis of the electroweak symmetry breaking sector in the Standard Model and its extensions, in signatures of New Physics models at colliders like the Large Hadron Collider (LHC), and in the non-perturbative, hadronic, low-energy structure of the strong interactions (QCD).

Hadronic light-by-light scattering contribution to the anomalous magnetic moment of the muon

I continued to work on the long-term project of studying the hadronic light-by-light scattering contribution to the muon $g-2$. Whereas the evaluation of the hadronic vacuum polarization contribution to the muon $g-2$ is likely to be improved considerably in the next few years with new experimental data on the cross-section $e^+e^- \to$ hadrons at various colliders, the estimates of hadronic light-by-light scattering are currently all based on hadronic models. This leads to large uncertainties in the Standard Model (SM) prediction for the anomalous magnetic moment of the muon and makes it difficult to interpret the presently observed deviation of about three to four standard deviations from the experimentally measured value as a clear sign of New Physics. In view of new planned muon $g-2$ experiments at Fermilab, USA, and at J-PARC, Japan, which aim at a factor of four-fold improvement in precision, it will be even more important to better control the hadronic uncertainties in the SM prediction of the anomalous magnetic moment of the muon.
Concerning the hadronic light-by-light scattering contribution, one important aspect is to know what are the relevant regions of momenta which enter in the respective multi-loop integrals. Theoretical constraints on the relevant Green's functions and hadronic form factors from perturbative QCD at high momenta (operator product expansion) and experimental data at low and intermediate momenta (in the region of hadronic resonances) can thereby reduce the model dependence of the current theoretical estimates of hadronic light-by-light scattering. I worked on these aspects for the numerically dominant exchange of the lightest pseudoscalars, in particular the neutral pion.

Publications:

1. A. Nyffeler, *Hadronic light-by-light scattering in the muon $g-2$: impact of proposed measurements of the $\pi^0 \to \gamma\gamma$ decay width and the $\gamma^*\gamma \to \pi^0$ transition form factor with the KLOE-2 experiment,* EPJ Web of Conferences **37**, 05002, (2012)

2. A. Nyffeler, *Hadronic light-by-light scattering in the muon $g-2$: impact of proposed measurements of the $\pi^0 \to \gamma\gamma$ decay width and the $\gamma^*\gamma \to \pi^0$ transition form factor with the KLOE-2 experiment,* PoS (Proceedings of Science) **CD12**, 045, (2013) (to be published)

Conference/Workshops Attended:

1. *Workshop on Meson Transition Form Factors*, Krakow, Poland, May 2012.
   Talk: Hadronic light-by-light scattering in the muon $g-2$: impact of transition form factor measurements

2. *12th International Workshop on Meson Production, Properties and Interaction (MESON 2012)*, Krakow, Poland, May-June 2012.
   Talk: Hadronic light-by-light scattering in the muon $g-2$: impact of proposed measurements of the $\pi^0 \to \gamma\gamma$ decay width and the $\gamma^*\gamma \to \pi^0$ transition form factor with the KLOE-2 experiment

3. *7th International Workshop on Chiral Dynamics*, Jefferson Lab, Newport News, VA, USA, August 2012.
   Talk: Hadronic light-by-light scattering in the muon $g-2$: impact of proposed measurements of the $\pi^0 \to \gamma\gamma$ decay width and the $\gamma^*\gamma \to \pi^0$ transition form factor with the KLOE-2 experiment

4. *RECAPP Workshop on Physics at the LHC*, HRI, November 2012.

Visits to other Institutes:

1. Institute for Theoretical Physics, University of Bern, Switzerland, May 2012 (2 weeks).

2. Institute for Theoretical Physics, University of Bern, Switzerland, February - March 2013.

Invited Lectures/Seminars:

1. *Hadronic light-by-light scattering in the muon $g-2$: impact of proposed measurements at KLOE-2 of the $\pi^0 \to \gamma\gamma$ decay width and the $\gamma^*\gamma \to \pi^0$ transition form factor*, Institute for Theoretical Physics, University of Bern, Switzerland, May 2012.

2. *Hadronic light-by-light scattering in the muon $g-2$*, Particle Theory Group, Yale University, New Haven, CT, USA, August 2012.

3. *Hadronic light-by-light scattering in the muon $g-2$*, Theoretical Particle Physics Group, Cornell University, Ithaca, NY, USA, August 2012.

Other Activities:

1. Graduate course at HRI: Particle Physics, August - December 2012.

2. Organization of "Sangam @ HRI: Instructional Workshop in Particle Physics" held at HRI in March 2013, together with Profs. S. Choubey, A.K. Datta, R. Gandhi, B. Mukhopadhyaya, S. Rai, V. Ravindran, October 2012 - February 2013.

3. Referee for European Physical Journal C, Journal of High Energy Physics (JHEP), Physical Review D.

Ramappa Prabhu

Research Summary:

During the academic year 2012-2013, I have carried out my research work on different aspects of quantum information theory. In particular, I investigated the behavior of quantum correlation and its usefulness in different quantum information processing tasks in multiparticle systems by collaborating with other members of the Quantum Information and Computation group at HRI.

Following are the succinct notes on the works done during this academic year:

- Quantum discord, an information-theoretic quantum correlation measure, can satisfy as well as violate monogamy, for three-party quantum states. We have quantified the feature using the concept of discord monogamy score. We found that a necessary condition of a vanishing discord monogamy score for arbitrary three-party states. This work is published in the journal Physcal Review A.

- Quantum correlation measures can be monogamous or non-monogamous for multisite quantum states. This can happen for measures within the entanglement- separability paradigm, as well as those in the information-theoretic one. We demonstrated that any quantum correlation measure that is non-monogamous for a multiparty quantum state can be made monogamous for the same by considering an increasing function of the measure.

- We have established a complementary relationship between the quantum advantage of the multiport classical capacity of a multiparty quantum state used as a quantum channel and the genuine multipartite entanglement of the multiparty state. The relation is demonstrated for two genuine multipartite entanglement measures the genuine multiparty relative entropy of entanglement and the generalized geometric measure. The relation holds for pure or mixed quantum states of arbitrary dimensions and of an arbitrary number of parties.

- We have investigated the advantage of using the genuine multiparty entanglement measure called generalized geometric measure for detecting quantum phase transitions in the infinite quantum spin-1/2

chains with two-spin isotropic XY interactions and three-spin interactions. We find that in contrast to bipartite entanglement, like concurrence, which signals to phase transitions that are not present, the generalized geometric measure faithfully detects the quantum phase transition in the system.

- We employed generalized geometric measure to predict phase diagrams in quantum many-body systems. We began by using the measure to detect the quantum fluctuation driven phase transition in an exactly solvable model, viz. the quantum XY model. We subsequently applied the generalized geometric measure to prototype frustrated quantum spin models, in the quasi two dimensional antiferromagnetic $J_1 - J_2$ model, the two dimensional antiferromagnetic $J_1 - J_2$ model and the Shastry-Sutherland model.

- We have established that in a tripartite scenario, the quantum advantage in multiport dense coding has a complementary relation with multiparty quantum correlation measures. We have analytically demonstrated that a single-parameter family of tripartite states, which we have called the maximally-dense-coding-capable quantum states, is best suited for sending classical information in a multiport dense coding protocol. This work is published in the journal Phyical Review A.

- We have shown that it is not only the Plancks constant but also quantum entanglement that plays an important role in setting the limits for the quantum uncertainties. This is attained by using the geometry of space of quantum states. This underlines the power of geometric ideas in quantum theory they help to bring together two of the most fundamental ingredients of quantum theory, namely, the "quantum of action" and the "quantum entanglement".

- We have studied the behavior of quantum correlations, both from the entanglement-separability paradigm and the information-theoretic one, of the equilibrium state as well as the evolved state of the quantum Heisenberg anisotropic XYZ model, by numerical simulations. In particular, we found that although entanglement measures are ergodic irrespective of the system parameters, information-theoretic measures exhibit a rich picture, with respect to their statistical mechanical properties.

Publications:

1. R. Prabhu, Arun Kumar Pati, Aditi Sen(De), and Ujjwal Sen, *Conditions for Monogamy of Quantum Discord: Monogamous Greenberger-Horne-Zeilinger versus Polygamous W states,* Phys. Rev. A **85**, 040102(R), (2012)

2. Manabendra N. Bera, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Characterization of Tripartite Quantum States with Vanishing Monogamy Score,* Phys. Rev. A **86**, 012319, (2012)

3. R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Dual quantum correlation paradigms exhibit opposite statistical mechanical properties,* Phys. Rev. A **86**, 012336, (2012)

4. R. Prabhu, Arun Kumar Pati, Aditi Sen(De), and Ujjwal Sen, *Relating monogamy of quantum correlations and multisite entanglement,* Phys. Rev. A **86**, 052337, (2012)

5. Rabindra Nepal, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Maximally-dense-coding-capable quantum states,* Phys. Rev. A **87**, 032336, (2013)

Preprints:

Conference/Workshops Attended:

1. *Symposium on Physics using the HPC facility*, India, August, 2012.

2. *International Conference on Quantum Information and Quantum Computing*, India, January, 2013.

Visits to other Institutes:

1. University of Warsaw, Warsaw, Poland, April 2012,

2. University of Düsseldorf, Düsseldorf, Germany, April 2012,

3. Bangalore University, Bengaluru, India, January 2013.

Invited Lectures/Seminars:

1. *Dichotomy of the Two Quantum Correlation Paradigms*, University of Warsaw, Warsaw, April 2012.

2. *Dichotomy of the Two Quantum Correlation Paradigms*, University of Düsseldorf, Düsseldorf, April 2012.

Academic recognition/Awards:

- INSPIRE Faculty Award, 2012.

Other Activities:

1. Mentored a numerical project of second year student, Uttam Singh, during Jan-May 2013.
2. Served as referee for the journals – Physical Review Letters, Physical Review A, and Pramana.
3. Serving as member of the Cluster Committee at HRI.

Kouhei Hasegawa

Research Summary:

I and my collaborators published one paper, whose title is Anomalous Higgs Interactions in Gauge-Higgs Unification, at Physical Review D87 **D87**, 016011, (2013). I attended the workshop, Sangam @ HRI, at March 2013. I visited Kobe University in Japan for my collaboration at April and October in 2012. I gave one review talk about dipole subtraction at Pheno-lunch at HRI on 1.May.2012.

Publications:

1. K. Hasegawa, Nobuaki Kurahashi, C.S. Lim, Kazuya Tanabe, *Anomalous Higgs Interactions in Gauge-Higgs Unification,* Physical Review D87 **D87**, 016011, (2013)

Preprints:

1. K. Hasegawa, Nobuaki Kurahashi, C.S. Lim, Kazuya Tanabe, *Anomalous Higgs Interactions in Gauge-Higgs Unification,* HRI-P-12-01-001 and 1201.5001 [hep-ph]

Conference/Workshops Attended:

1. *Sangam @ HRI: Instructional Workshop in Particle Physics*, India, March 2014.

Visits to other Institutes:

1. Kobe University, Kobe, Japan, Octorber 2012.
2. Kobe University, Kobe, Japan, April 2012.

Invited Lectures/Seminars:

1. *A basic of dipole subtraction,* Pheno-lunch, HRI, 01.May.2012.

Joint Colloquia

1. S.M. Roy: Testing Causal Quantum Mechanics by Joint Quadrature Measurements.
2. Partha Ghosh: New Mathematical Insights into human cognition.
3. Amitava Raychaudhuri: The Higgs boson and its discovery for non experts.
4. Rajesh Gopakumar: Ashoke Sen and Fundamental Physics.
5. Subir Sachdev: Quantum Entanglement and Phases of Matter.
6. Quevedo Fernando: The Large Hadron Collider, Our Universe and String Theory.
7. Charles H BEnnett: Quantum Information, the ambiguity of the past and the complexity of the present.
8. Klaus von Klitzing: New from Quantum Hall Physics.
9. Rob TijdemanL Mathematical Theory of Discrete Tomography.

Mathematics Talks and Seminars

1. Claire Levaillant: A quantum combinatorial approach for computing a tetrahedral network of Jones-Wenzi projectors.
2. Rama Mishra: An introduction to Knot theory.
3. Rob Tijeman: Mathematical theory of discrete tomography.
4. Michel Waldschmidt: Liouville Sets and Liouville fields.
5. Krishnendu Gangopadhyay: On the Classification of Unitary Matrices.
6. Krishnendu Gangopadhyay: On Palindromic Width in Free Nilpotent Groups.
7. C.S. Dalawat: Primitive Extension.
8. Ritwik Mukherjee: Counting Curves via Topology
9. Hiroyuki Yamane: Coxeter semigroups and representation theory
10. Hiroyuki Yamane: Nichols topology inside Zariski topology
11. Hiroyuki Yamane: Harish Chandra theorem of generalised quantum groups
12. Rama Mishra: Knot Theory and Physics
13. Rama Mishra: Knot Theory and Physics

Physics Talks and Seminars

1. Aranya Bhattacharjee: Opto-mechanical effects in self-organization of a Bose-Einstein condensate in an optical cavity.
2. Satoshi Ohya: 1D Topological Insulators in Optical Lattice.
3. Arnab Rudra: Mellin amplitude in AdS/CFT.
4. Masazumi Honda: Numerical studies of the ABJM theory of arbitrary N at arbitrary coupling constant.
5. Shyamal Biswas: The critical Casimir force in the superfluid phase: Effect of Fluctuations.
6. Sourav Bhattacharya: Some studies on de Sitter black hole spacetimes.
7. Amitava Moitra: Magnesium Alloy Design: A perspective on multiscale modeling.
8. Saptarshi Mandal: Some many body aspect of Kitaev model and its generalisation.
9. Swapna Mahapatra: Non-holomorphic deformation, duality covariant variable and Hesse potential in $N = 2$ supergravity.
10. Saikat Ghosh: Coupling Photons one-at-a-time to Single Quantum Emitter.
11. Shasanka Mohan Roy: Noiseless Quantum Tracking and Quantum Tomography.
12. Amol B. Rahane: Theoretical Study of Structural, Magnetic and Optical Properties of Metal Oxide Nanostructures.
13. Ranjan Laha: Searching for dark matter using Neutrinos and radio waves.
14. Aloke Gupta: Multi-wavelength Variable and Quasi Periodic Oscillation (QPOs) in Blazars.
15. Dibakar Roychowdhury: Thermodynamics of Hawking -Page transition in Ads black hole.

16. Arnab Kundu: Dynamics of Fundamental Flavours in Holographic Duals of Large N Guage Theories.

17. Sourav Mitra: Physics of cosmological reionization.

18. Sushan Konar: Neutron Star: A ball of rotating superfluid with a metallic crust!

19. Prabodh Shukla: Voter Model Dynamics: Coarsening and Persistence.

20. Prabodh Shukla: Effect of Quenched Disorder on Domains and Interfaces.

21. Golam Ali Sekh: Displaced dynamics of binary Bose-Einstein condensates in linear and nonlinear optical lattices.

22. Kanak Saha: Structure and evolution of disk galaxies: impact of dark matter halos.

23. Ipsita Mandal: Amplitude Mode of the d-Density Wave State and its Relevance to High-T_c Cuprates.

24. Siddhartha Sinha: Higher signal harmonics, LISA's angular resolution and dark energy.

25. V. V. Ravi Kishore: Electronic structure of InAs/GaSb core-shell nanowires.

26. Vijay Kumar: Calabi-Yau manifolds from Gauge Theories.

27. Rathin Adhikari: Finding CP violation, hierarchy of neutrino masses and non-standard interactions in neutrino experiments.

28. Quevedo Fernando: Aspects of Large volume Scenario in String Theory.

29. Surhud More: Galaxy-Dark Matter Connection: A cosmological perspective.

30. Sandeep K Goyal: Qudit-teleportation for photons with linear optics.

31. Lukas Witkowski: A story of de-and re-coupling: supersymmetry breaking in string models.

32. SP Hovarth: Amplitudes for space-like separations and causality.

33. Aftab Alam: Electronic structure, Phonons and Phase stability of disordered materials.

34. Partha Ghosh: Entangled Classical Light.

35. Partha Ghosh: A versatile method of entangling a pair of independently generated single-photons.

36. Imtak Jeon: Supersymmetric Double Field Theory.

37. Abhijit Samanta: Precision studies in neutrino sector: signatures and constraints on new physics.

38. Jaehoon Jeong: Massless gravitation of noncritical gravity.

39. Samrat Bhowmik: Type black brane solution and anisotropic cosmology.

40. Sanhita Modak: Spin Injection into a metal from a topological insulator.

41. Oleg Evnin: Reduced models and the large D expansion.

42. Rodrigo Olea: Kounterterms in anti-de Sitter gravity.

43. Olivera Miskovic: Holography and Weyl anomalies in AdS3 gravity with torsion

44. Shinji Shimasaki: Exact results for theories with SU (2/4) Symmetry.

45. Masahide Manabe: Exact Kahler potential for Calabi-Yau Fourfolds.

46. Samir Mathur: The black hole information paradox.

Recent Graduates

1. **Jaban Meher**, *Some Problems on Modular Forms*.
2. **Satyanarayan Mukhopadhyay**, *New Physics with low missing-energy: identification and discrimination at the LHC*.
3. **Amrutiya S. K. Hansraj**, *On Tannakian Fundamental Group Schemes, and on Real Parabolic Vector Bundles over a Real Curve*.
4. **Nishita Desai**, *Signals of supesymmetry and Higgs at the LHC*.
5. **Vivekanand Singh**, *The impact of antisite disorder on magnetism and transport in the double perovskites*.
6. **Dhiraj Hazra**, *Primordial Features and Non-Gaussianites*.
7. **Shailesh Lal**, *Higher-Spin Theories and the AdS/CFT Correspondence*.

Publications

Publications (Mathematics)

Sukumar Das Adhikari

1. Sukumar Das Adhikari and Purusottam Rath, *Remarks on monochromatic configurations for finite colorings of the plane,* Note di Matematica, **32**, no. 2, 83 –88 (2012).

2. Sukumar Das Adhikari, *An extremal problem in combinatorial number theory*, Proceedings of he Legacy of Srinivasa Ramanujan Conference held in Delhi during Dec 17-22, 2013, (to appear).

Ramakrishnan B.

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About the Computer Section

1. Newer versions of different flavors of Linux operating systems were installed on the desktops.
2. New versions of several applications software were loaded on users' systems, computer centre and conference room systems.
3. All the primary servers such as Mail, Webmail, DNS, SSH, DHCP, Proxy, LDAP and Firewall were upgraded with new ones and with newer version of operating systems and other packages.
4. Computing related to conferences were held in the conference computer room.
5. Computer Centre's NIS client machines were upgraded to LDAP clients with newer versions of operating systems and other packages.
6. New black and white laser printers were installed on the network.

Current activities and plans

1. Purchase of about 20 desktops for Ph.D. students is under plan.
2. Upgradation of scientific software with new versions are under plan.

Library

The Institute's library is one of the best-equipped libraries in the region. Being the library of a research institute, it provides the required support to the academic and research activities. It remained open on all working days between 8 a.m. to 2 a.m. including Saturdays. It also remained open during the Sundays and the Gazzetted holidays from 10 a.m. to 6 p.m. It had added 402 (Four hundred and two) books including gifted books 72 in its fold. It increased the total number of books to 20850 (Twenty thousand eight hundred and fifty) which includes 999 books as gifted books. It has also added 17 bound volumes of the journals during the period from 1st April 2012 to 31st March 2013, it has increased bound volumes collection to 35219. The institute's library has a total collection of 56059 (Fifty six thousand and fifty nine) of books and bound volumes. The library had subscribed to 225 journals during this period, it includes 110 as online journals.

The physical stock verification has been recently completed with the help of PDT (Portable Data Terminal) for collection of Bar Codes. Since the whole collection is 'Bar Coded' and equipped with 'Tattle Tapes' for security. It reflected no loss of titles in either books or journals.

The 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 have planned for 2.5 folds increase in our present space. The construction of the same is also in the full swing which will allow the library space increasing horizontally. Recently we had provided better and latest systems to our users for browsing the library OPAC and related search. We enriched our Building of the Digital Depository of the HRI, which includes the submitted articles, thesis, lectures etc. The library web page has been updated which provides more 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 also given to procure maximum number of journals online. We have been providing on-line access of the periodicals to our users for 96 (Ninety six) titles.

We javeprovided the Web Enabled library catalogue to its users. The library can be termed as completely automated library system, which includes acquisition, cataloguing, circulation, search modules etc. The on-

line catalogue had increased the opportunities of the use of our library resources by the neighboring organizations such as INSDOC, TIFR etc. through the Document Delivery Services (DDS). Normally we provide the DDS on request through post, at very nominal cost, but requests had also been honored through e-mails. We encouraged the use of its library by providing library consultation facilities to the research scholars from the neighboring institutes. We strengthened its library security with the implementation of Electro-magnetic Tattle Tapes to reduce losses. This has been made completely functional.

Construction Activity

1. Construction work of Engineering building and Community Centre Annexe has been completed.
2. Construction of Married Block Apartment was completed.
3. Following miscellaneous works were also carried out during the financial year :
    - Renovation of Mess in Hostel-I building.
    - Supply and installation of Automatic fire alarm system in Auditorium.
    - Associated Electrical works related to Community Centre Air-conditioning.
    - Renovation works in Community Centre.
    - Laying Hume pipe (RCC) for storm water drainage near New Hostel building site.
    - Pull down arrangement for three white writing boards in lecture room.
    - Supply, installation, fixing and Commissioning of chimney for Hostel-I Mess.
    - Supply and fixing vertical blind and Sun control film on the windows of Engineering building.

Note: Construction activities from February-2013 was affected due to order of Hon'ble High court 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 fall within this prohibited range. HRI has filed an application in Court for relief against this order as HRI has its own Sewage Treatment Plant (STP) with almost zero discharge and cannot cause pollution to river Ganges. The decision of Court is our case is still awaited.