Academic Report – 2013–14

Harish-Chandra Research Institute

Chhatnag Road, Jhunsi, Allahabad 211019

Contents

About the Institute

Early Years

The Harish-Chandra Research Institute is one of the premier research institutes in the country. It is an autonomous institute fully funded by the Department of Atomic Energy, Government of India. Till October 10, 2000 the Institute was known as Mehta Research Institute of Mathematics and Mathematical Physics (MRI) after which it was renamed as Harish-Chandra Research Institute (HRI) after the internationally acclaimed mathematician, late Prof Harish-Chandra.

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

Prof. Shrikhande was followed by Prof. H. S. Mani who took over as the Director in January 1992. With his joining and the shift to the new campus at Jhunsi in 1996, the Institutes activities picked up pace. This phase of rapid growth still continues.

New Phase

After a distinguished tenure of about nine years Prof. Mani retired in August 2001 and the charge was taken over by Prof. R. S. Kulkarni. After Prof. Kulkarnis tenure, Prof. Amitava Raychaudhuri was the Director from July 19, 2005 to May 15, 2011. Prof. Jayanta Kumar Bhattacharjee,

the current Director, took over in April 29, 2012. The Institute continues to be devoted to fundamental research in diverse areas of mathematics and theoretical physics. Research is carried out by faculty members, visiting members, post-doctoral fellows and Ph. D. students.

Since 1992 the Institute has attracted worldwide attention, as is evident from the recognition received by many of its members. Several members of the Institute have been recognised for their scientific contribution. Prof. B. Mukhopadhyaya, Prof. Pinaki Majumdar, Prof. Rajesh Gopakumar and Prof. Ashoke Sen have been awarded the S.S. Bhatnagar prize for work done at HRI. Prof. Gopakumar has also received the Swarnajayanti Fellowship of the Department of Science & Technology and the ICTP Prize for 2006. The outstanding contribution of Prof. Ashoke Sen has been recognised by a Fellowship of the Royal Society, the award of Padmashri and Padmabhushan and the award of one of the first Fundamental Physics Prize (2012) from the Yuri Milner Foundation. He was the only recipient of the prize from all of Asia.

Prof. Rajesh Gopakumar was awarded the TWAS physics prize in October 2013 and he won the G D Birla prize in physical sciences for the year 2013 earlier this year. Prof. Aditi Sen De received the Buti foundation award of the Indian Physics Association for the year 2013. Prof. Raj Gandhi was awarded the Fermilab Intensity Fellowship which would allow him to work at Fermilab for a considerable period.

Research in Mathematics

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

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

Research in Physics

Research in Physics at HRI is carried out in the fields on astrophysics, condensed matter physics, quantum information and computing, high energy phenomenology and string theory. In astrophysics, work is done on 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 theory, supersymmetry and various aspects of physics beyond the standard model is done in high-energy phenomenology. The Institute is a member of the India-based Neutrino Observatory (INO) collaboration. The Institute has a residential campus in Jhunsi, Allahabad with a library, state of the art computational facility and fast Internet link to the outside world. There is an active graduate program and a large traffic of visiting scientists and students.

Director's report

Once again the past year (2013-2014) was eventful for HRI scientist. Prof. Ashoke Sen was given M.P. Birla Golden Jubilee Award, Prof. Rajesh Gopakumar won the G.D. Birla award and the TWAS physics prize, Prof. Aditi Sen De was awarded the Buti Foundation prize and Prof. B. Ramakrishnan and Dr. A.K. Pati were elected fellows of the National Academy of Sciences, India. In addition, one of our ex-students Dr. Soumya Das (currently at IISc., Bangaluru) was given Young Scientist award. That certainly is a lot of recognition for a small institute like ours.

Academic activities flourished with a significant number of important publications in physics and mathematics. The number of applications for our integrated Ph.D. programme and the regular Ph.D. programme and the number of Post-Doctoral applications remained high as ever. Short term visitors arrived almost every week and the visiting student programme (VSP) remained extremely popular. The winter months saw a spate of conferences and workshops. The Physics groups organised the meeting on Quantum Information Processing an Applications during 02-08 Dec., 2013, the Strings group organised a Workshop on Black Hole Information Paradox during 03-06 Feb., 2014, the Condensed Matter Group organised a Conference on Transport in Topological Insulators: during 09-12 July, 2013, School and Workshop on Physics of Cold Atoms during 10-16 Feb., 2014 and also The Third International Symposium on Clusters, Cluster Assemblies and Nano Scale Materials (ISCANM-III) during 11-14 March, 2014. Prof. Boris Keyser of Fermilab gave a general talk on Neutrinos get under your skin on 28th March, 2014 for the Foundation Day lecture which was jointly organised by the High Energy Physics Group (RECAPP & Neutrino). The High Energy Physics Group also organised The Instructional Workshop on Particle Physics Sangam@HRI 2014 during 24-29 March, 2014. The Mathematics Group organised a workshop on Harmonic Analysis, Topology and Geometry, Algebraic Curves, Schurs multipliers and IMS lecture series in HRI. This year the IMS lecture was given by Mahan Maharaj of Vivekanand University, Belur. The summer program in mathematics (SPIM) continued to draw eager participants from across the country. This program for college students which exposes them to learn mathematics by thought and reason is extremely popular and draws students from neighbouring countries as well. 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 test in mathematics and physics for school students on the Allahabad area. Students of 10th and 12th grade from various schools in Allahabad appeared for the test. The toppers were awarded prizes in a special function organised in HRI which was held in 18th February, 2014. The high point of the evening was an enthralling lecture by Prof. Joseph Oesterle of University of Paris on Ramanujan.

The stalemate in construction persists as the last year because of the order passed by the Allahabad High Court in a public interest litigation of 2006 about the pollution of Ganga. This year has also been marked by the visit of several DAE officials on the administration front. Under Secretary (Budget), Deputy Controller of Accounts, Joint Secretary (Finance and R & D), Director of Administration visited during this year for various discussions. Also, HBNI Director visited the Institute and had a long discussion with faculty regarding the academic expansion of the Institute. He also met our graduate students. There have been some changes on the personnel front. Prof. Sudhakar Panda has been given lien to join as Director, IOP, Bhubaneswer. While Mr. Umesh Kumar Singh, Stores Purchase Officer has been given lien to join Indian Zoological Survey of India, Kolkata. Dr. Hemangi Shah has joined the Mathematics faculty. Mr. Prabhat Kumar, P.A. to Director has retired in the course of the year.

Jayanta Kumar Bhattacharjee

List of Governing Council Members

(2013 -14)

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
13. Dr. Hemangi M. Shah

Faculty Members (Physics)

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

8. Prof. Dileep Jatkar
9. Prof. Pinaki Majumdar
10. Prof. 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 A.K. Srivastava [SO (SB) (Electrical)]
8. Shri V.K. Srivastava [SO (SB) (Civil)]
9. Shri Jagannath Yadav [Accountant]
10. Shri R.P. Sharma [Manager Guest House]
11. Ms. Archana Tandon [Office Superintendent]
12. Ms. Anju Verma [Scientific Assistant]
13. Shri U.K. Dwivedi [Cashier]
14. Shri D. Malhotra [Upper Division Clerk]
15. Shri K.K. Srivastava [Upper Division Clerk]
16. Shri Yashpal Singh [Stenographer]
17. Ms. Sumitra [Upper Division Clerk]
18. Ms. Seema Agarwal [Receptionist]
19. Mr. Om Kumar Karn [Junior Hindi Translator]
20. Shri Umesh Kumar Singh [Store/Purchase Officer]
21. Shri P.N. Mishra [Jr. Lib. Assistant]
22. Shri D.P. Sharma [Jr. Lib. Assistant]
23. Shri Sanjeev Nagar [Hindi Typist]

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

Visiting Fellow

Mathematics

1. Dr. Bhavin K. Moriya
2. Dr. Vipul Kakkar
3. Dr. Kuntal Banerjee
4. Dr. Makoto Sakagaito

Physics

1. Dr. Efgnwande Osoba
2. Dr. Masahide Manabe
3. Dr. Sourav Bhattacharya
4. Dr. Kenji Nishiwaki
5. Dr. Kouhei Hasegawa
6. Dr. Anindya Biswas
7. Dr. Manabendra Nath Bera
8. Dr. Abhinav Saket
9. Dr. Richard Garavuso
10. Dr. Yoshinori Homma
11. Dr. Madhuparna Karmakar
12. Dr. Arindam Chatterjee
13. Dr. Ambresh Kumar Shivaji
14. Dr. Trilochan Bagarti
15. Dr. Debraj Rakshit
16. Dr. Menika Sharma
17. Dr. Reetanjali Moharana

18. Dr. Suprabh Prakash
19. Dr. Tomohisa Takimi
20. Dr. Namrata Shukla
21. Dr. Masazumi Honda
22. Dr. Tanumoy Mandal
23. Dr. Amit Kumar Pal

Visiting Scientist

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

Research Scholar

Mathematics

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

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

NBHM Students (Mathamatics)

(a) Mr. Bhawani Singh
(b) Mr. Abhishek Juyal

Physics

1. Mr. Ram Lal Awasthi
2. Mr. Manoj Kumar Mandal
3. Mr. Saurabh Niyogi
4. Mr. Arunabha Saha
5. Mr. Ujjal Kumar Dey
6. Mr. Saurabh Pradhan
7. Mr. Vikas Chauhan
8. Mr. Sabyasachi Tarat
9. Mr. Nyayabanta Swain
10. Mr. Abhishek Chowdhury
11. Mr. Swapnamay Mondal
12. Ms. Akansha Singh
13. Ms. Shrobona Bagchi

14. Mr. Mehedi Masud
15. Mr. Avijit Misra
16. Mr. Narayan Rana
17. Mr. Maguni Mahakhud
18. Ms. Avinanda Chaudhuri
19. Mr. Utkarsh Mishra
20. Ms. Ushoshi Maitra
21. Mr. Udit Narayan Chawdhury
22. Mr. Roji Pius
23. Mr. Taushif Ahmed
24. Mr. Aritra Gupta
25. Mr. Abhishek Joshi
26. Mr. Shankha Banerjee
27. Mr. Uttam Singh
28. Mr. Kadge Samrat Suresh
29. Mr. Dibya Kanti Mukherjee
30. Mr. Arijit Dutta
31. Mr. Soumyadeep Chaudhuri
32. Mr. Sauri Bhattacharya
33. Mr. Saikat Banerjee
34. Mr. Tamoghna Das
35. Mr. Krashna Mohan Tripathi
36. Mr. Asutosh Kumar
37. Mr. Debasis Mondal
38. Mr. Ashis Kumar Pal

39. Mr. Nabarun Chakrabarty
40. Mr. Aditya Banerjee
41. Mr. Udit Khanna
42. Mr. Ali Sarosh Ansar
43. Mr. Aloke Kumar Sinha
44. Ms. Ajanta Maity
45. Mr. Harshant Singh
46. Mr. Debasis Sadhukhan
47. Mr. Sudipto Singha Roy
48. Mr. Mritunjay Kumar Verma
49. Mr. Sitender Pratap Kashyap
50. Ms. Juhi Dutta
51. Mr. Titas Chanda
52. Mr. Ankur Das
53. Mr. Subhroneel Chakrabarti
54. Mr. Satadal Datta
55. Mr. Jyotiranjan B.
56. Mr. Kasinath Das
57. Mr. Rishu Kumar Singh
58. Ms. Ruchi Saxena
59. Md. Arif Shaikh
60. Mr. Siddharth Dwivedi
61. Mr. Gautam Sharma
62. Mr. Chiranjib Mukhopadhyay
63. Mr. Ritabrata Bhattacharya

64. Mr. Sarif Khan
65. Mr. Dhruv Pathak
66. Mr. Shouvik Roychoudhury
67. Ms. Sreetama Das
68. Mr. Dipyaman Pramanik
69. Mr. Sandeep Kumar Sehrawat
70. Mr. Samiran Roy
71. Mr. Abhass Kumar

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. A conjecture has been formulated for finite commutative semigroups generalizing some classical results in the case of finite abelian groups; in a joint work with some collaborators this conjecture has been verified in some classes of important finite commutative semigroups, including group-free semigroups, elementary semigroups, and archimedean semigroups with certain constraints. Some new results have been obtained in the area of zero-sum problems with weights. Work is in progress on some questions of monochromatic solutions of certain equations.

Publications:

1. Sukumar Das Adhikari, *An extremal problem in combinatorial number theory*, Proceedings of an International Conference in Celebration of the 125th Anniversary of Ramanujan's Birth; University of Delhi, 17-22 December 2012, (Eds. Bruce C. Berndt and Dipendra Prasad), 1–11, Ramanujan Mathematical Society Lecture Notes Series, Number 20, (2013).

2. Sukumar Das Adhikari, *Schur's theorem in combinatorial number theory: Some generalizations,* J. Indian Math. Soc. (Special Volume) 1–10 (2013).

3. Sukumar Das Adhikari, Weidong Gao and Guoqing Wang, *Erdős-Ginzburg-Ziv theorem for finite commutative semigroups,* Semigroup Forum, To appear, Published online on 14 November 2013.

4. Sukumar Das Adhikari and Eshita Mazumdar, *Modifications of some methods in the study of zero-sum constants,* Integers, To appear.

Conference/Workshops Attended:

1. *Ramanujan's Mathematics and IT (RMIT 2013)*, International Institute of Information Technology, Bangalore (IIITB), India, June, 2013.

2. *"Modern methods in Combinatorics", ECOS 2013*, Universidad Nacional de San Luis, Argentina, July 22 to August 2, 2013.

3. *Thue 150*, Bordeaux, France, September 30 - October 4, 2013.

4. *Number Theory and Discrete Mathematics*, Chandigarh, India, Nov 11-12, 2013.

5. *Analytic Theory of Automorphic forms*, IMSc-CMI, Chennai, Dec 9-13, 2013.

6. *Ramanujan's Mathematics and its applications*, Panna (M.P.), India, December 22-23, 2013.

Visits to other Institutes:

1. Institute of Information Technology, Bangalore (IIITB), India, June, 2013.

2. Universidad Nacional de San Luis, Argentina, July-August, 2013.

3. UPMC Paris 6, Jussieu, France, September, 2013.

4. Institut de Mathématiques de Bordeaux, Université Bordeaux I, France, September-October, 2013.

5. Aix-Marseille University, France, October, 2013.

6. Indian Statistical Institute, Delhi, November, 2013.

7. Department of Mathematics, Hyderabad Univ, November, 2013.

8. University of North Bengal, India, January, 2014.

9. Ramakrishna Mission Vivekananda University, Belur, India, March, 2014.

Invited Lectures/Seminars:

1. *Some zero-sum problems and Ramsey-type results in Additive Combinatorics*, Modern methods in Combinatorics, A course of lectures in the CIMPA school ECOS 2013, San Luis, Argentina, July 22 to August 2, 2013.

2. *Classical Ramsey-type results in Additive Combinatorics and Monochromatic configurations for finite colorings of the plane*, Séminaire CAESAR de combinatoire additive, UPMC Paris 6, Jussieu, 26th September, 2013.

3. *A problem regarding visibility of integer lattice points and related questions*, Department Seminar, Aix-Marseille University, France, 8th October, 2013.

4. *Some old and new results on zero-sum problems with with weights* $1, -1$, Conference on Number Theory and Discrete Mathematics, Department of Mathematics, Panjab University, Panjab University, Chandigarh, On the occassion of 70th birthday of professor R.J. Hans Gill, Held during Nov 11-12, 2013.

5. *Two early Ramsey-type results: Some generalizations and applications*, Department Seminar, Indian Statistical Institute, Delhi, 20th November, 2013.

6. *Some zero-sum problems in additive combinatorics*, Department Seminar, Hyderabad Univ, 22nd November, 2013.

7. *Some omega results related to the error terms in the averages of arithmetical functions*, Analytic Theory of Automorphic forms, IMSc-CMI, Chennai, Dec 9-13, 2013.

8. *Zero-sum theorems in finite abelian groups*, Refreshers Course in Mathematics, University of North Bengal, India, January 10-11, 2014.

9. *A classical result on set addition and some zero-sum results in combinatorial number theory*, Number Theory Seminar, Department of Mathematics, IIT, Mumbai, 13th March, 2014.

Academic recognition/Awards:

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

Other Activities:

1. Currently Dean, Administration at HRI.

2. Currently working as a member of 'the National Board for Higher Mathematics' (NBHM).

3. A member of the editorial board of 'The Journal of the Indian Mathematical Society'.

4. A member of the editorial board of 'Bulletin of the Calcutta Mathematical Society'.

5. Working as a member of the editorial board of the periodical 'Mathematics Newsletter' published by Ramanujan Mathematical Society.

6. Gave a course on Number Theory to M. Sc students at RKMV University, Belur, upto April 18, 2013.

7. Gave a talk *Congruences, squares and sums of squares* at the INSPIRE INTERNSHIP SCIENCE CAMP at Raj Kumar Goel Engineering College, Ghaziabad, held during May 13th to May 17th, 2013.

8. Gave a course on field theory at SPIM at HRI in the week June 18-22, 2013.

9. Gave some lectures in the Refresher Course in Mathematics organized by Academic Staff College, University of North Bengal during January 10-11, 2014.

10. Gave a course of lectures and a seminar at RKMV University, Belur, during March 3-10, 2014.

Ramakrishnan Balakrishnan

Research Summary:

1. Convolution sums of the divisor functions and some applications (joint works with Brundaban Sahu). In the first work, we evaluated the convolution sums $\sum_{a+12b=n} \sigma(a)\sigma(b)$ and $\sum_{3a+4b=n} \sigma(a)\sigma(b)$ using the theory of quasi-modular forms. As an application, by comparing the earlier work on the evaluation of these convolution sums by Alaca-Alaca-Williams with our present formulas, we obtain certain interesting consequences on the expression of certain newforms of weight 4 on $\Gamma_0(6)$ and $\Gamma_0(12)$. In our second work, we have evaluated the convolution sums $\sum_{l,m\in\mathbf{N},l+2m=n} \sigma_3(l)\sigma_3(m)$, $\sum_{l,m\in\mathbf{N},l+3m=n} \sigma_3(l)\sigma_3(m)$, $\sum_{l,m\in\mathbf{N},2l+3m=n} \sigma_3(l)\sigma_3(m)$ and $\sum_{l,m\in\mathbf{N},l+6m=n} \sigma_3(l)\sigma_3(m)$ for all $n \in \mathbf{N}$ using the theory of modular forms. As an application we used these convolution sums to determine the number of representations of a

positive integer n by the quadratic forms $Q_8 \oplus Q_8$ and $Q_8 \oplus 2Q_8$, where the quadratic form Q_8 is given by

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

In our next work (which is in progress), we compute triple convolution sums of the divisor functions and further compute the number of representations of a positive integer by certain quadratic forms.

2. Jacobi forms and differential operators (joint work with Soumya Das). In this work, we affirmatively answer a question due to 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. This is a refined version of our earlier work.

Publications:

1. B. Ramakrishnan and Karam Deo Shankhadhar, *On the restriction map for Jacobi forms,* Abh. Math. Semin. Univ. Hamburg **83**, 163–174, (2013)

2. B. Ramakrishnan, *Modular forms of half-integral weight,* The Mathematics Student **81**, 101–114, (2012)

Preprints:

1. B. Ramakrishnan and Brundaban Sahu, *On the number of representations of an integer by certain quadratic forms in sixteen variables,* Accepted for publication in Int. J. Number Theory

2. B. Ramakrishnan and Brundaban Sahu, *On the convolution sums* $\sum_{a+12b=n} \sigma(a)\sigma(b)$ *and* $\sum_{3a+4b=n} \sigma(a)\sigma(b)$, Submitted.

3. B. Ramakrishnan and Brundaban Sahu, *Evaluation of the convolution sums of divisor functions and certain applications*, (in preparation).

4. Soumya Das and B. Ramakrishnan, *Jacobi forms and differential operators*, Submitted.

Conference/Workshops Attended:

1. *International Conference on Ramanujan's Mathematics and IT (RMIT 2013)*, IIIT, Bangalore, India, June 2013.
2. *Workshop and International Conference on Automorphic Forms and Number Theory*, KSOM, India, August/September 2013.
3. *Explicit Theory of Automorphic Forms*, Shanghai, China, March 2014.

Visits to other Institutes:

1. RWTH, Aachen & University of Siegen, Siegen, Germany, April/May 2013.
2. The Institute of Mathematical Sciences, Chennai, India, November 2013.

Invited Lectures/Seminars:

1. *Chinese Remainder Theorem and its Applications*, RMS-UGTE programme, Lady Shri Ram College for Women, New Delhi, November 2013.
2. *Jacobi forms and differential operators*, Explicit Theory of Automorphic Forms, Tongji University, Shanghai, China, March 2014.

Academic recognition/Awards:

- Elected Fellow of the National Academy of Sciences, India, 2013.

Other Activities:

1. One of the organisers of the Workshop and International Conference on Automorphic Forms and Number Theory (a joint activity of HRI and KSOM) held at KSOM during August/September 2013.
2. Coordinator of the Talent Search Examination (Mathematics) for school children conducted by HRI during November 2013.
3. One of the organisers of the Annual Foundation School - I (a programme of the National Centre for Mathematics) held at the Kerala School of Mathematics, Kozhikode, December 2013.

Punita Batra

Research Summary:

A Lie Torus is a multi-loop algebra with some more conditions on it. With S. E. Rao, work is going on in finding the irreducible, integrable modules for Lie torus with finite dimensional weight spaces with respect to its Cartan subalgebra.

Publications:

1. S. Eswara Rao, Punita Batra and Sachin S. Sharma, *The irreducible modules for the derivations of the rational quantum torus,* J. of Algebra **410**, 333-342, (2014).

Visits to other Institutes:

1. School of Mathematics, TIFR, Mumbai, October 13-19, 2013.

Other Activities:

1. Gave two lectures in the Rajbhasha scientific workshop at HRI in May 2013.

2. Gave two lectures in the "Hands-on training in Mathematics" for secondary school students at HRI on June 19, 2013. This programme was organised by NASI, Allahabad under Science Communication Programme.

3. Gave six lectures on " Galois Theory" in Summer Programme in Mathematics(SPIM) at HRI in June, 2013.

4. Gave first year graduate course Topology-I during August-December 2013.

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

Kalyan Chakraborty

Research Summary:

In a joint work with S. Kanemitsu and T. Kuzumaki we have studied the incomplete gamma function expansion of the Epstein zeta functions attached to a positive definite quadratic form, which are known as Ewald expansions. From these expansions we could derive many well known results e.g., Bochner–Chandrasekharan theorem, Atkinson–Berndt theorem etc. In another joint work again with the same authors we give an alternate expression for the class number formula for the real quadratic fields when the discriminant $d \equiv 5 \pmod 8$. Work in in progress on a similar problem in the case of imaginary quadratic fields.

It is interesting to study the 'torison fields' which arose by attaching torsion points of an elliptic curve to $\mathbb{Q}$. Properties like what are the Galois groups that occur and how the Galois groups are related to the corresponding class groups are extremely interesting. I am exploring few interesting questions along these lines with my students.

Publications:

1. K. Chakraborty, S. Kanemitsu and T. Kuzumaki*On the class number formula of certain real quadratic fields,* Hardy-Ramnujan journal **36**, 1–7, (2013)

2. K. Chakraborty, S. Kanemitsu and T. Kuzumaki*On the Barnes multiple gamma functions,* Siauliai Math. Sem.,(2014)

Preprints:

1. K. Chakraborty, S. Kanemitsu and T. Kuzumaki *Ewald expansions of certain zeta functions,*

2. K Chakraborty and Makoto Minamide *On the power moments of the Hecke multiplicative functions,*

3. K. Chakraborty, *On the class number formula of certain imaginary quadratic fields.*

Visits to other Institutes:

1. Kyoto Sangyo University, Kyoto, Japan, June 2013,
2. Kinki University, Fukuoka, Japan, August 2013.

Invited Lectures/Seminars:

1. *Arithmetic Fouries series and the modular relations*, Number Theory seminar, Kytoto Sangyo University, Kyoto, June 2013.
2. *Introduction to Cryptography*, Inspire Program, Pt. Ravishankar university, Raipur, September 2013.

Other Activities:

1. Co-ordinate NBHM MA/M.Sc and Ph.D. Fellowship Examinations.
2. Refereeing Papers, Reviews for AMS.

Chandan Singh Dalawat

Research Summary:

For local fields K with finite residue field of prime characteristic p and cardinality q, we determined all galoisian extensions of degree l^3 for a prime $l \neq p$. For example, when $p \neq 2$, then K has a galoisian extension of degree 2^3 which is not abelian if and only if $q \equiv 3 (\mathrm{mod}\ 4)$; if so, it has a unique quaternionic extension and a unique dihedral extesnion. If l is odd and if K has a galoisian extension L of degree l^3 which is not abelian, then l divides $q-1$ but l^2 does not, and conversely. In this case, the group $\mathrm{Gal}(L|K)$ is isomorphic to the neutral extension of $\mathbf{Z}/l\mathbf{Z}$ (viewed as a subgroup of $(\mathbf{Z}/l^2\mathbf{Z})^\times$) by $\mathbf{Z}/l^2\mathbf{Z}$.

More generally, all tamely ramified extensions of a local field have been parametrised in a natural manner and the role of group cohomology has been brought to the fore. This is joint work with Dr Jung-Jo Lee of the University of Seoul.

Preprints:

1. C S Dalawat & J-J Lee, *Tame ramification and group cohomology*, 32 pp., `arXiv:1305.2580`.

Invited Lectures/Seminars:

1. *Tame ramification and group cohomology*, Indian Institute of Technology, Bombay, 25 June, 2013 ; Indian Institute of Science Education and Research, Bhopal, 30 September, 2013.

2. *What is a reciprocity law ?*, Mathematics Seminar, Indian Institute of Science Education and Research, Bhopal, 2 September 2013.

3. *Classical reciprocity laws : a recreation*, Mathematics Seminar, Indian Institute of Science Education and Research, Poona, 4 January 2014 ; Mohali, 18 February 2014 ; Indian Institute of Technology, Kanpur, 10 March 2014 ; Tata Institute of Fundamental Research, Bombay, 25 March 2014.

Other Activities:

Acted as Mentor for the Inspire Science Camp (DST) at Rama Krishna College, Satna, on 18/6/2013 and gave a talk on *Sums of two, three, four squares and beyond*. Supervised two undergraduate students from NISER Bhubaneshwar in July 2013. Examind the thesis, and acted as an external examiner during the viva voce of a doctoral student of the University of Punjab. Mentored an undergraduate student from IIT Madras in Decemeber 2013. Refereed some papers for international journals.

Rukmini Dey

Research Summary:

During this year, my main focus has been research on Constant Mean Curvature surfaces, jointly with my student, Rahul Kumar Singh. We have completed the work on interpolation of two closed real analytic curves by piecewise minimal surfaces (mean curvature zero), and prepared a joint paper with Pradip Kumar and Rahul Kumar Singh. Now we have started to look into the interpolation problem of two closed real anayltic curves by constant mean curvature surfaces of non-zero mean curvature (CMC

surfaces). Secondly, we are examining the question of when CMC are algebraic curves (i.e. locally given by the zero set of a polynomial of 3 variables). Of the regular CMC surfaces, it is known that only the sphere and the cylinder (and the planar minimal surfaces) are algebraic. We are investigating the non-regular cases. There are many examples of non-regular minimal surfaces which are algebraic curves. We are investigating the cases of the non-regular CMC surfaces which are not minimal.

In addition I continued my work on quantization. In particular, I studied the possibility of quantization of vortices using Biswas and Romao's embedding of the vortex moduli space into projective space. I also studied the [Q, R] =0 conjecture and made some progress on proving it.

In addition, I have continued my work on quantization, in particular quantization of vortex configuration space.

Preprints:

1. Rukmini Dey, Pradip Kumar, Rahul Kumar Singh, *Piecewise minimal surfaces interpolating between two real analytic curves* , (in preparation).
2. Rukmini Dey, Dilip Jatkar, Samir Paul, *Geometric prequantization of the Hamiltonians in finite Toda systems,* (in preparation)
3. Rukmini Dey, *Ramanujan's identities, minimal surfaces and solitons*, (in preparation)
4. Indranil Biswas, Saikat Chatterjee, Rukmini Dey, *Geometric prequantization on the path space of a prequantized manifold,* (in preparation).

Conference/Workshops Attended:

1. *Discussion Meet: Real Variable Methods in Harmonic Analysis, HRI, Allahabad*, India, Sept, 2013.
2. *28th Annual RMS Conference, Reva Institute, Bangalore*, India, June, 2013.

Visits to other Institutes:

1. Reva Institute, Bangalore, India, June, 2013,
2. S.N. Bose Center, Kolkata, India, May-June, 2013.

Lectures/Seminars:

1. *Geometric Quantization and Coherent States*, Discussion Meet on Real Variable Methods in Harmonic Analysis, HRI, Allahabad, September, 2013.

2. *Some Aspects of Minimal Surfaces*, 28th Annual RMS conference, Reva Institute, Bangalore, June, 2013.

3. *Geometric Quantization and Coherent States*, S.N. Bose Center, Kolkata, May, 2013.

Other Activities:

1. Instructor, Topology II, August-December, 2013.

2. Organizer: Instructional School for Lecturers on Topology and Geometry, HRI, Dec 16th to 28th, 2013.

3. Guiding 2 PhD students, Mr. Pradip Kumar and Rahul Kumar Singh.

4. Attended various committees

Ratnakumar Peetta kandy

Research Summary:

I have worked on four problems in the last one year jointly with my collaborators. The first one is concerned with a Hardy sobolev inequality for the twisted laplacian, jointly with Vijay Kumar Sohani and Adimurthi. The twisted Laplacian on $\mathbb{C}^n$ refers to the magnetic laplacian in the plane corresponding to n particles in the plane acted upon by a magnetic potential perpendicular to the plane. Thus our result extends the previously known result for the Laplacian on $\mathbb{R}^n$ to the case of magnetic Laplacian for n particles in the plane acted upon by a constant magnetic field. The approach involves the spectral theory of the twisted Laplacian.

The second work on square functions associated to the bilinear multipliers on $\mathbb{R}^n$, jointly with Saurabh Kumar Shrivastava, is an extension of our own previous work for square functions corresponding to smooth multipliers. In this work, we could prove optimal estimates for square function

corresponding to much more general multipliers than the multipliers considered in our previous work, in which the multipliers were just translates of a single function.

The other two projects involves my Ph. D students, Divyang Bhimani and Ramesh Manna. Divyang's work concerns with study of wellposedness of Schrödinger equation on modulation spaces, which involves the study of action of nonlinearity on the modulation spaces. We have characterised nonlinearities, that operates on the modulation space $M^{p,1}_s(\mathbb{R}^n)$. One of the consequence of this result is that the standard method to study wellposedness in modulation spaces exploiting the algebra property, can be extended at most to handle real entire non linearities. In particular it throws light on the fact that the power type nonlinearity of the form $F(u) = |u|^\alpha u$, that is interesting from application point of view, requires new approach, when α is not an even integer.

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

Preprints:

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

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

3. Ratnakumar P K and Saurabh Kumar Shrivastava, *A remark on bilinear Littlewood-Paley square functions* (preprint)

Conference/Workshops Attended:

1. *ATMW Analysis and Geometry*, TIFR CAM, Bangalore, India, January 2014.

Visits to other Institutes:

1. Kerala School of Mathematics, Calicut, India, December 2013,

2. Indian Institute of Science, Bangalore, India, January 2014.

3. TIFR CAM, Bangalore, India, January 2014.

Invited Lectures/Seminars:

1. *Lectures in Topology*, Advanced Foundational School-I , Kerala School of Mathematics, Calicut, December 2013.

2. *Lectures in Analysis*, Advanced Foundational School-I, Kerala School of Mathematics, Calicut, December 2013.

3. *Story of integration*, Math Seminar, Thunjan memorial college, Thirurangadi, Calicut, December 2013.

4. *Bilinear multipliers and Littlewood-Paley square functions*, Conference on Harmonic Analysis and Operator Theory, IISER, Bhopal, March 2014.

Other Activities:

1. Organised the discussion meeting "Real variable Methods, An instructional School in Harmonic Analysis" during 23-30th of September 2013.

2. Served as the convener in the guest house and the pantry committee, since July 2013.

3. Served as the convener in the horticulture committee since August 2013.

Manoj Kumar

Research Summary:

The Bogomolov multiplier $B_0(G)$ of a finite group G is defined as the subgroup of the Schur multiplier consisting of the cohomology classes vanishing after restriction to all abelian subgroups of G. A finite group G is said to be rigid if $|Out_c(G)| = 1$, where $Out_c(G)$ denotes the group of class-preserving outer automorphisms of G. Jointly with Pradeep K. Rai, we computed $|Out_c(G)|$ for all p-groups G of order p^6, where p is an odd

prime. As an application, we provide an affirmative answer to the following question of Kang and Kunyavskiĭ for all group of order p^6: Is it true that $B_0(G) = 0$ for all rigid group?

Jointly with Mike Newman, we studied groups of order p^7 whose automorphism group is abelian. A group G of order p^7 is said to be of complexity $(4, 3)$ if the Frattini subgroup of G is elementary abelian of order p^3. We proved that a group of order p^7 whose automorphism group is elementary abelian with order p^{12} is a special group of complexity $(4, 3)$. We further show that there are at least $p^5 + 2p^4 + 2p^3$ groups with complexity $(4, 3)$ whose automorphism group is elementary abelian with order p^{12} for $p \geq 13$. This work is still in progress.

Publications:

1. Manoj K. Yadav, *On subgroups generated by small classes in finite groups,* Comm. Algebra **41**, 3350 - 3354, (2013)

2. Manoj K. Yadav, *On finite p-groups whose central automorphisms are all class preserving,* Comm. Algebra **41**, 4576 - 4592, (2013)

3. Vivek K. Jain, Pradeep K. Rai and Manoj K. Yadav, *Finite p-groups with abelian automorphism group,* Internat. J. Algebra Comput **23**, 1063 - 1077, (2013)

Preprints:

1. Pradeep K. Rai and Manoj K. Yadav, *On rigidity of groups of order p^6,* Preprint

Conference/Workshops Attended:

1. *Instructional School of Schur Multiplier and Related Topics*, India, March 2014.

Visits to other Institutes:

1. Dept. of Mathematics, the Australian National University, Canberra, Australia, April - September, 2013.

Invited Lectures/Seminars:

1. *Basic group theory*, RMS Undergraduate Teachers Enrichment (UGTE) Program, Deshmukh College, New Delhi, February 2014.

2. *History of solving polynomial equations*, DST INSPIRE Program for School Students, SP Memorial Institute of Technology, Allahabad, December 2013.

3. *Class-preserving automorphisms and central quotients of finite p-groups*, Algebra and Topology Seminar, MSI, the Australian National University, Canberra, September 2013.

4. *Class-preserving automorphisms and central quotients of finite p-groups*, Algebra Seminar, Mathematics Dept, University of Sydney, Sydney, September 2013.

5. *Central factor and commutator subgroup of nilpotent groups*, Computational Algebra Seminar, Mathematics Dept, University of Sydney, Sydney, Ausgust 2013.

Other Activities:

1. Examined a Ph. D. Thesis for mathematics department of Allahabad University, Allahabad, January 2014.

2. Refereed papers for many national and international journals.

3. Organised "Instructional School on Schur Multiplier and Related Topics" at HRI, March 01 - 08, 2014 (jointly with Vipul Kakkar and Pradeep Rai).

4. Gave an advanced course on Schur multiplier at HRI, January - May 2014.

5. My biography got published in Marquis, Who's Who in the world - 2013.

6. Got Indo-Russian research collaboration project for three years (2013-2016) jointly with other members.

Raghavendra Nyshadham

Research Summary:

I have been working on vector bundles over real algebraic varieties. I have also been working on generalisations of the Atiyah-Weil criterion for the existence of holomorphic or algebraic connections in vector bundles.

Invited Lectures/Seminars:

1. *Topology (six lectures)*, SPIM, HRI, Allahabad, June 2013.
2. *Resolution of singularities of curves (five lectures)*, Algebraic Curves, HRI, Allahabad, February–March 2014.

Other Activities:

1. Taught a first-year graduate course on Differential Manifolds in the second semester of the academic year 2013–2014.
2. Have been guiding a second-year student (S. Manikandan) in his project.
3. Guided a first-year student (Pradeep Das) for his seminar.
4. Was a member of the Security Committee of 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. The results of Helfgott and Roton were further improved by Eric Naslund. 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. Let $L := a_1x_1 + a_2x_2 + \cdots + a_s$ be a lineal equation. We say that L is *translation invariant* if $\sum_i a_i = 0$. Moreover a solution of L is said to be trivial if $x_1 = x_2 = \cdots = x_s$ and it is said to be non-trivial otherwise. We show that for any translation invariant linear equation with the number of variables $s = 3$ and admissible $\widetilde{h}_k$, a dense subset of $C_{\widetilde{h}_k}$ contains infinitely many non-trivial solution of L. Earlier, we had proved this for $L := x_1 + x_2 - 2x_3 = 0$.

Recently, borrowing a result from a preprint of Kevin Henriot, we have been able to generalise this result for any translation invariant linear equation. When $k = 1$ and $\widetilde{h}_1 = (0)$ and $L := x_1 + x_2 - 2x_3 = 0$, this gives us the result of Helfgott and Roton mentioned above, while when $k = 2$, and $\widetilde{h}_2 = (0, 2)$ and $L := x_1 + x_2 - 2x_3 = 0$, 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. In the ongoing work, we are trying to generalise the result for a system of translation invariant linear equation of complexity one.

Preprints:

1. Gyan Prakash, *A remark on a result of Helfgott, Roton and Naslund* arxiv:1403.7609

Conference/Workshops Attended:

1. *Analytic Theory of Automorphic Forms*, India, December 2013.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, October 2013,
2. Institute of Mathematical Sciences, Chennai, India, December 2013,
3. Institute of Mathematical Sciences, Chennai, India, March 2014,

Invited Lectures/Seminars:

1. *A generalisation of Roth's Theorem in primes*, Analytic Theory of Automorphic forms, Institute of Mathematical Sciences, Chennai, December 2013.

Other Activities:

1. Acted as a convenor of Sports and Entertainment committee (sports) since 1st November 2013.

2. Acted as a member of Medical committee during 2013-2014.

D Surya Ramana

Research Summary:

It is well-known that every natural number is a sum of four squares and likewise, that every sufficiently large natural number is the sum of no more than four prime numbers. Following A. Sárközy one may ask for a chromatic versions of these facts. Contributing to this theme, we showed, together with P. Akhilesh, that for each $\epsilon > 0$ there is a $C(\epsilon) > 0$ so that when the set of squares of natural numbers is coloured with K colours, K an integer ≥ 1, then each sufficiently large integer can be written as the sum of no more than $C(\epsilon)K^{2+\epsilon}$ squares, all of the same colour. This result improves on an earlier result of N. Hegyvári and F. Hennecart who obtained $(K \log K)^5$ in place of our $K^{2+\epsilon}$. It also complements an earlier result of ours, with O. Ramaré, which dealt with the case of primes. In work in progress, we consider the possibility of improving our bound from $K^{2+\epsilon}$ to $K^{1+\epsilon}$, in addition to pursuing a number of other threads within the theme of Sárközy's problems. If the aforementioned improvement is obtained, it would be an essentially optimal answer to Sárközy's problem for the squares. Our methods generalise easily to cover higher powers of the natural numbers as well.

Publications:

1. P. Akhilesh and D.S. Ramana, *A Chromatic Version of Lagrange's Four Squares Theorem,* to appear in Monatshefte für Mathematik, 2014.

2. D.S. Ramana, *Representation of Integers as Chromatic Sums of Primes,* Proceedings of the Conference Legacy of Ramanujan, Lecture Notes in Mathematics, Ramanujan Math. Soc., No. 20, pp. 335-346, 2013.

Conference/Workshops Attended:

1. Gave a lecture in *Analytic theory of automorphic forms*, Chennai, India, December 2013.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, December, 2013 to January, 2014.

Other Activities:

1. Taught Algebra II from Jan to May 2014.
2. Served as Convenor of Graduate Committee in Mathematics, Library Committee and as member of the Local Works Committee.
3. Supervised the work of G. Kasi Viswanadham, P. Akhilesh, K. Mallesham and Bhuvanesh Rao Patel towards their respective theses as also the annual seminars of E. Pramod and Mithun Das, all graduate students at HRI.

Visits to other Institutes:

1. Institute of mathematical sciences, Chennai, India, December-January 2013-14.

Hemangi Madhusudan Shah

Research Summary:

I worked extensively on harmonic and asymptotically harmonic spaces from 1st May 2014 - 31st March 2014. The research summary is briefed as follows :

Harmonic Spaces :

1. Rank of harmonic manifolds :
   Let (M,g) be a complete, simply connected and non-compact harmonic manifold. We show that geometric rank of M is one. The proof uses the idea of uniform divergence of geodesics and some standard concepts in differential geometry.

2. An elementary proof of the theorem: Harmonic Manifolds With Minimal Horospheres Are Flat :
   We give an elementary approach to prove the theorem that harmonic manifolds with minimal horospheres are flat. The known proof uses very complicated ideas in the theory of harmonic spaces.

3. Rigidity of harmonic structures :
   Let (M,g) be a complete, simply connected non-compact harmonic manifold. We show that, if M is flat or a Rank One Symmetric Space, then M is rigid as a harmonic space. We also establish that the collection of all harmonic structures on a given manifold is a compact space with respect to smooth topology. This implies that, if a harmonic manifold is non-deformable, then there are only finitely many isometry classes of harmonic manifold.

Asymptotically Harmonic Spaces :

1. On 3- dimensional asymptotically harmonic manifolds with minimal horospheres :
   Let (M,g) be a complete, simply connected and non-compact Riemannian without conjugate points. We show that if M is an asymptotically harmonic manifold of dimension 3 with minimal horospheres, then M is flat.

Publications:

1. Hemangi M Shah, *A new proof of the theorem: harmonic manifolds with minimal horospheres are flat,* Proc. Indian Acad. Sci (Mathematical Sciences), (to appear), (2014).

Preprints:

1. Hemangi M Shah, *Rank of harmonic manifolds,* submitted for publication.

2. Hemangi M Shah, *On 3- dimensional asymptotically harmonic manifolds with minimal horospheres,* submitted for publication.

3. Hemangi M Shah, *Rigidity of harmonic structures,* preprint .

Conference/Workshops Attended:

1. *The Ramanujan Mathematical Society's Annual Meeting*, India, June, 2013.

Invited Lectures/Seminars:

1. *On Rank of Harmonic Manifolds*, Seminar in Topology and Geometry at RMS meeting, Reva Institute of Technology, Bangalore, India, June, 2013.

Ravindranathan Thangadurai

Research Summary:

Schanuel's conjecture states that if $x_1, x_2, \ldots, x_n$ are linearly independent over $\mathbf{Q}$, then among the numbers $x_1, x_2, \ldots, x_n, e^{x_1}, e^{x_2}, \ldots, e^{x_n}$, at least $n+1$ are algebraically independent. We proved that there are uncountably many Liouville numbers satisfy this conjecture. Moreover, we proved a stronger version of this conjecture for such an uncountable set. In another paper, we have studied unique representation of integers with given base A. We characterized the bases for which number of summands required to write a given integer n in the given base A is $\log \log n$.

Publications:

1. K. Senthil Kumar, R. Thangadurai and M. Waldschmidt, *Liouville numbers and Schanuel's Conjecture*, Arch. Math. (Basel), **102**, 59-70, (2014)

2. M. Ram Murty and R. Thangadurai, *On the parity of the fourier coefficients of j-function*, *To appear in:* Proc. Amer. Math. Soc. (Series A).

3. R. Thangadurai and K. Viswanadham, *On the prime k-tuple conjecture*, *To appear in:* Integers.

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

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

6. S. Subburam and R. Thangadurai, *On the Diophantine equation* $x^3 + by + 1 - xyz = 0$, *To appear in:* C. R. Math. Acad. Sci. Soc. R. Can.

Preprints:

1. S. Subburam and R. Thangadurai, *On norm form Diophantine equations*, (in preparation).
2. M. Ram Murty and R. Thangadurai, *On some diophantine equation*, (in preparation).
3. A. Mukhopadyay, R. Thangadurai and K. Viswanadham, *Unique representation of integers with base* A, (in preparation).

Conference/Workshops Attended:

1. *AIS - Analytic Number Theory*, India, June, 2013.
2. *CIMPA - ICTP School on 'Algebraic Curves over finite fields and applications*, Philippines, July, 2013.
3. *Refresher course for College Teachers in Kerala State on 'Algebra'*, India, October, 2013.
4. *Analytic Theory of Automorphic Forms*, India, December, 2013.
5. *AFS - I*, India, December, 2013.
6. *Number Theory Symposium on Ramanujan's Birthday*, India, December, 2013.
7. *Discussion Meeting on 'Algebraic Curves'*, India, February, 2014.

Visits to other Institutes:

1. KIIT, Bhubaneswar, India, June, 2013.
2. University of Philippines, Manila, Philippines, July, 2013.
3. KSOM, Calicut, India, October, 2013.
4. Institute of Mathematical Sciences, Chennai, India, December, 2013.
5. KSOM, Calicut, India, December, 2013.
6. SASTRA University, India, December, 2013.

Invited Lectures/Seminars:

1. *Sieve Methods*, AIS - Analytic Number Theory, KIIT, Bhubaneswar, June, 2013.

2. *Modules over PID*, Refresher course for College Teachers in Kerala State on 'Algebra' , KSOM, Calicut, October, 2013.

3. *Algebra*, AFS - I, KSOM, Calicut, December, 2013.

4. *Schanuel's Conjecture and Liouville numbers*, Number Theory Symposium on Ramanujan's Birthday, SASTRA University, December, 2013.

Other Activities:

1. Organized 'Summer Programme in Mathematics (SPIM 2013)' at HRI, June, 2013.

2. Gave 'Analysis - I' graduate course during August- December, 2013.

3. Organized 'Analytic Theory of Automorphic Forms' at IMSc, Chennai, December, 2013.

4. Organized 'Discussion Meeting - II on 'Algebraic Curves' at HRI, Allahabad, February, 2014.

5. Convener of Transport Committee, HRI, during 2013.

6. Co-guide of Mr. S. Subburam who defended his Ph. D thesis at SASTRA University, Tanjore in December 2013.

7. Guiding Mr. K. Senthil Kumar, Mr. Pallab Dey and Mr. Balesh Kumar for their thesis, while guided Ms. Ritika Sharma and Mr. Nabin Meher for their first year Seminar Course.

8. Refereed papers for the internationl journals.

Satya Deo

Research Summary:

During this Academic Year 2013-2014, I have been working on my DST research project entitled "Topological Methods and Combinatorial mathematics" which has been almost completed. The other project entitled

"Combinatorics via Algebraic Topology" approved by the NASI under the Senior Scientist Fellowship programme is in progress. By now I have studied and understood various generalizations of the Kneser-Lovasz Theorem and also the different generalizations of the Birch-Tverberg Theorem, specially the colored version of these theorems. Two publications have come out of these works which have been accepted for publication, one in Mathematics Student of the Indian Mathematical Society and the other in the journal "Clifford Algebra, Clifford Analysis and Applications" (CRC Press). I have also been working as the Editor-in-Chief of the Journal of Indian Mathematical Society from April 2013.

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

Publications:

1. Satya Deo, *Index of a finitistic space and a generalization of the topological central point theorem,* Journal of Ramanujan Mathematical Society **28**, 223-232, (2013)

2. Satya Deo, *Combinatorial 8-manifolds like projective plane and their non-embeddings,* New Zealand J. Mathematics, (2013).

3. Satya Deo, *Topological Combinatorics-Kneser Conjecture,* Mathematics Student, **83**, 01-16, (2014).

4. Satya Deo, *Topological Combinatorics- Tverberg theorem and generalizations,* Clifford Analysis, Clifford Algebra and Applications, (2014)

Preprints:

1. *The colored Theorem of Blagojevic, Matschke and Ziegler* , (in preparation).

Conference/Workshops Attended:

1. *Scientific Paper Writing Lecture Workshop*, University of Udaipur, Rajasthan, organized by NASI, April 5-7, 2013.

2. *Three Science Academies' Lecture Workshop*, organized by NASI, IIIT and HRI, Allahabad, June 24-26, 2013.

3. *INSPIRE Conference of DST*, organized by Raipur University, Raipur, July 16-18, 2013.

4. *Instructional School for Lecturers on Geometry and Topology* organized by HRI, Allahabad under the ATM programme of NBHM, Dec 2013.

5. *Annual Conference and a Symposium on Topology*, organized by the Indian Math Soc. at Rajagiri Institute of Science and Technology, Cochin, Dec 27-30, 2013.

6. *International Conference on Recent Developments in Mathematics*, Nagpur University, Nagpur Jan 20-23, 2014.

Visits to other Institutes:

1. University of Udaipur, Rajasthan, to give an invited lecture on Scientific Paper writing Lecture Workshop organized by NASI, April 5-7, 2013.

2. Bharwari Science College, Bharwari, Kaushami to give a talk as a Guest of Honour, May13, 2013.

3. IIT, Kanpur to give a keynote address in the Workshop of Utsahi Physics Teachers, organized by NASI on June 26, 2013.

4. Raipur University, Raipur for giving an invited lecture under the INSPIRE programme of DST, July 16-18, 2013.

5. Raipur Science College, Raipur to give a lecture on Algebraic Topology, July 16-17, 2013.

6. Mathematics Department, Agra University Agra, to give an invited talk on "Birch Conjecture" Sep 23-24, 2013.

7. Tata Institute of Fundamental Research, Mumbai, Oct 21-16, 2013.

8. DVD College, Lucknow to give a lecture on Interdisciplinary Mathematics in a conference organized in honour of Prof Sunil Datta, October 18-20, 2013.

9. Mathematics Department, University of Lucknow, to give a lecture during the Annual conference of the Bharat Ganit Parishad, Nov 29-30, 2013.

10. NASI Annual Session held the Institute of Oceanography, Goa, Dec 5-7, 2013.

11. Rajagiri Institute of Science and Technology, to orgaize a symposium on Topology, Cochin, Dec 27-30, 2013.

12. Nagpur University, Nagpur to participate in the International Conference on Recent Developments in Mathematics, Jan 20-23, 2014.

Invited Lectures/Seminars:

1. *What is a good research problem in Mathematics?*, Scientific Paper Writing Lecture Workshop, University of Udaipur, Rajasthan, organized by NASI, April 5-7, 2013.

2. *Solving Polynomial equations- Abel and Galois*, Rajbhasha Programme for Secondary School Students organized at HRI, Allahabad, May 14-15, 2013.

3. *On Geometric constructions and Galois Theory,* Three Science Aacademies' Lecture Workshop, organized at IIIT, Allahabad. June 24-26, 2013.

4. *On Sets and Maps- in Memory of Prof H.C.Khare,* Three Science Aacademies' Lecture Workshop, organized at NASI, Allahabad, June 24-26, 2013.

5. *Geometric Constructions with ruler and Compass*, INSPIRE Programme of DST, Raipur University, Raipur, July 16-18, 2013.

6. *On Simplicial Homology*, ATM school on Geometry and Topology, organized by HRI Allahabad, Dec 16-26, 2013.

7. *On Topological Combinatorics-Birch Conjecture and Generalizations*, Annual conference of the Indian Mathematical Society, Rajagiri Institute of Science and Technology, Cochin, Dec 27-30, 2013.

8. *On Topological Combinatorics-Tverberg Theorem and Generalizations*, Internationa;l Conference on Recent Advances in Mathematics, Nagpur University, Nagpur, Jan 20-23, 2014.

9. *On topological Combinatorics- Birch's Conjecture*, Invited lecture, South Asian University, New Delhi, Feb 11, 2014.

Academic recognition/Awards:

- Chief Guest in the function honoring Pt Manik Chandra Mishra, a Sanskrit scholar of Allahabad, Oct 11, 2013.
- Member, DST Programme Advisory Committee in Mathematical Sciences, 2013-2015.
- Chief Editor, J. Indian Mathematical Society, 2013-2016..
- Editor, Proc of National Academy of Sciences (Physical Sciences), India, 2012-2016.
- Editor, Indian J. Mathematics, 2012-2015.
- Senior Scientist Platinum Jubilee Fellow, NASI, Allahabad, 2013-2015.
- Honorary Treasurer and Council Member, NASI, Allahabad, 2012-2015.

Other Activities:

1. Member, NBHM Interview Board for MSc Scholarships and PhD scholarships at HRI, 2013-2014.
2. NASI Extension Lecture organized at Maharshi Durbasa Inter College, Kakara, Allahabad, Nov 2013.
3. NASI extension lecture delivered at Sangram Garh Intermediate College in Pratagarh.
4. Member, NASI Science Communication Programme, 2013-2014.

Debika Banerjee

Research Summary:

Linearized product of two Riemann Zeta functions: In a joint work with Jay Mehta, we elucidated the well-known Wilton's formula for product of two Riemann-Zeta Functions. A proof of Wiltons expression for product of two zeta functions was given by M. Nakajima using Atkinson dissection. On the similar line we derived Wiltons formula using Riesz sum of the order $\kappa = 1$.

On an analogue of Butchstab's Identity: We considered sums of the type $\psi(x, y; f) = \sum_{n \leq x, p|n \Rightarrow p<y} f(n)$ and $\phi(x, y; f) = \sum_{n \leq x, p|n \Rightarrow p>y} f(n)$ for different arithmetical functions f and proved their asymptotic behaviours and their applications. This is a joint work with Prof. Makoto Minamide.

A note on square-free numbers with restricted prime factors(Joint work with Prof. Makoto Minamide) :A. Ivic showed an asymptotic formula for the number of square-free integers n not exceeding x, whose prime factors are not exceeding y. In this paper, we changed the above condition prime factors $\leq y$ to $< y$. We deduced an analogue of Buchstab identity and an asymptotic formula for the modified function.

On the number of k-free integers with restricted prime factors(Joint work with Prof. Makoto Minamide):A. Ivic deduced the formula for the number of k-free positive integers not exceeding x whose prime factors are not exceeding y. In this paper,we deduced an analogue of Buchstabs identity for k-free integers, and obtained a sharper result when x and y are large.

Preprints:

1. Debika Banerjee and Jay Mehta, *Linearized product of two Riemann Zeta functions* (accepted in Proc. of Japan Acad. Sci.).

2. Debika Banerjee and Makoto Minamide, *On an analogue of Butchstab's Identity* , (in preparation)

3. Debika Banerjee and Makoto Minamide, *A note on square-free numbers with restricted prime factors* , (in preparation)

4. Debika Banerjee and Makoto Minamide, *On the number of k-free integers with restricted prime factors,* (in preparation)

Conference/Workshops Attended:

1. *AIS in Analytic Number Theory*, KIIT School of Computer Applications, KIIT University, Bhubaneswar, India, 10th June -30th June 2013.

2. *Conference on Analytic Theory of Automorphic Forms*, IMSc, Chennai, India, 9- 13 December, 2013.

Divyang G. Bhimani

Research Summary:

We denote $\mathcal{S}(\mathbb{R}^d)$ and $\mathcal{S}'(\mathbb{R}^d)$ the Schwartz space and its dual spaces, respectively; and the short-time Fourier transform (STFT) of f with respect to a window $g \in \mathcal{S}(\mathbb{R}^d)$ is $V_g f(x,w) = \int_{\mathbb{R}^d} f(t)\overline{g(t-x)}e^{-2\pi i w\cdot t}dt,\ (x,w) \in \mathbb{R}^{2d}$, when ever integral make sense. Then for $1 \leq p,q \leq \infty$, and for given a non zero smooth rapidly decreasing function $g \in \mathcal{S}(\mathbb{R}^d)$, we define the Weighted modulation spaces $M^{p,q}_s(\mathbb{R}^d)$ consists of all tempered distributions $f \in \mathcal{S}'(\mathbb{R}^d)$ for which, the following norm is finite:

$$\|f\|_{M^{p,q}_s} = \left(\int_{\mathbb{R}^d}\left(\int_{\mathbb{R}^d}|V_g f(x,w)|^p dx\right)^{q/p}(1+|w|^2)^{qs/2}dw\right)^{1/q},$$

with the usual modification if p or q are infinite. We put, $M^{p,q}_0(\mathbb{R}^d) = M^{p,q}(\mathbb{R}^d)$. In 2006, W. Baoxiang, Z. Lifeng, and G. Boling have proved estimate,

$$\|f|f|^\alpha\|_{M^{p,1}(\mathbb{R}^d)} \leq \|f\|^{\alpha+1}_{M^{p,1}(\mathbb{R}^d)};$$

for $\alpha \in 2\mathbb{N}$, $1 \leq p \leq \infty$, and $f \in M^{p,1}(\mathbb{R}^d)$; and for $\alpha \in (0,\infty)\setminus 2\mathbb{N}$, the open question has been raised by, Michael Ruzhanskya, Mitsuru Sugimotob, Baoxiang Wang, for the same. We have investigated this problem, and surprisingly, we have given its answer to be negative; infect, we have proved the following result: If $F(f) \in M^{p,1}(\mathbb{R}^d)$, for every $f \in M^{p,1}(\mathbb{R}^d)$, where $F(f)$ be the composition of functions F and f, then $F(0) = 0$ and F must be real-analytic on $\mathbb{R}^2$. Also, on the other-hand, we have shown that, If F is real-entire on $\mathbb{R}^2$, then $F(f) \in M^{p,1}(\mathbb{R}^d)$ whenever $f \in M^{p,1}(\mathbb{R}^d)$, and $F(f) \in M^{p,q}_s(\mathbb{R}^d)$ whenever $f \in M^{p,q}_s(\mathbb{R}^d), (d \in \mathbb{N}, 1 \leq p,q \leq \infty, s > d/q', 1/q + 1/q' = 1)$.
Secondly, as an application, we have obtained local well-posedness results for the nonlinear Shrödinger equation(NLS), nonlinear wave equation (NLW) and nonlinear Klein-Gordon equation (NLKG) equations with

nonlinearities included is of real-entire type and Cauchy data in modulation spaces $M^{p,1}_s(\mathbb{R}^d), (1 \leq p \leq \infty, s \geq 0)$; and also in $M^{p,q}_s(\mathbb{R}^d), (1 \leq p, q \leq \infty, s > d/q')$.

Conference/Workshops Attended:

1. *ATM Workshop Analysis and Geometry*, TIFR-CAM Bangalore, India, 6-10 January 2014.
2. *Real Variable Methods in Harmonic Analysis*, HRI Allahabad, India, 23-30 September 2013.
3. *Advanced Instructional Schools Analysis and Geometry,* TIFR-CAM Bangalore, India, 8-27 July 2013.

Invited Lectures/Seminars:

1. *Complex Analysis*, Summer Programme in Mathematics (SPIM 2013), Harish Chandra Research Institute, Allahabad, June-July 2013.
2. *Tutor*, Annual Foundation School - Part I, Kerala school of Mathematics, Kozhikode, December 2013.

Pallab Kanti Dey

Research Summary:

I am studying elliptic curves and algebraic number theory. Basically I have studied the "Chebotarev density theorem" and applied it to some analogous result related to Artin's primitive root conjecture. Also I am trying to see some other applications of "Chebotarev density theorem".Now I am working on finding all the torsion points in quadratic fields for a given elliptic curve over raionals. Also I am reading elliptc curves with complex multiplication and Galois representation. Also, I am trying to learn basics of Hilbert modular forms and trying to understand its properties associated to number fields.

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 (2014).

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

3. Pallab Kanti Dey,*Q(i)-torsion points of elliptic curves*, (in preparation).

Conference/Workshops Attended:

1. *Advanced Instructional Schools on Analytic number theory, June 10-30, 2013, KIIT, Bhubaneswar, India.*

2. *Conference on Analytic Theory of Automorphic Forms, December 9-13, 2013, IMSC, Chennai, India.*

3. *Discussion meeting on algebraic curves-2, March 9-14, 2014, HRI, Allahabad, India.*

Visits to other Institutes:

1. Kerala School of Mathematics, 10-27 march 2014, Kerala, India.

Other Activities:

1. tutor for Discussion meeting on algebraic curves-2, 19-5 march 2014, HRI, Allahabad, India.

Kasi Viswanadham G

Research Summary:

We say that a set $A \subseteq \mathbb{N}$ is a *set of uniqueness* if $f(A) = 0$ implies $f \equiv 0$ for any completely additive function f. In 1964, I. Katai proved that the set of shifted primes $\mathcal{P} + 1 = \{p + 1 |\ p \text{ is a prime}\}$ together with finite set of primes is set of uniqueness. In a joint work with Jay Mehta, we proved an analogues result to the Katai's result in the case of Gaussian integers.

In a joint work with Jay Mehta and Biswajyoti Saha, we obtain the meromorphic continuation of multiple zeta functions, together with a complete list of their poles and residues, by means of an elementary and simple *translation formula*. We also express this translation formula in terms of matrices which is a more efficient way for studying poles are residues of multiple zeta functions. We extended our results to certain natural weighted variants of multiple zeta functions.

Publications:

1. Jay Mehta and G. K. Viswanadham, *Quasi uniqueness of the set of Gaussian prime plus ones,* To appear in International Journal of Number Theory.

2. R. Thangadurai and G. K. Viswanadham, *On prime $k-$tuple conjecture,* To appear in Integers.

Preprints:

1. Anirban Mukhopadhyay, R. Thangadurai and G. K. Viswanadham, *Unique Representation of Integers With Base A,* (Preprint).

2. Jay Mehta, Biswajyoti Saha and G. K. Viswanadham, *On The Analytic Continuation of Multiple Zeta functions,* (In preparation).

Conference/Workshops Attended:

1. *Analytic theory of automorphic forms*, Chennai, India, December 2013.

Visits to other Institutes:

1. Institute of mathematical sciences, Chennai, India, December-January 2013-14.

Mallesham K

Research Summary:

For any $A \subseteq \mathbb{N}$, we define the *additive representation* function $r_A : \mathbb{N} \to \mathbb{R}$ by

$$r_A(n) = |\{(a,b) \in A^2 \mid n = a+b;\ a,b \in A\}|,$$

which was introduced by Paul Erdös and P. Turán in 1941. They defined asymptotic 2-basis as: *a set A is said to be asymptotic 2-basis for $\mathbb{N}$ if there is $n_0 \in \mathbb{N}$ such that $r_A(n) \geq 1, \ \forall \ n \geq n_0$*. They conjectured that if A is asymptotic 2-basis for $\mathbb{N}$ then the sequence $\{r_A(n)\}_{n=1}^{\infty}$ is unbounded; it is still an open problem. I have been reading research papers and related texts which are concerned with this problem.

Conference/Workshops Attended:

1. *A discussion meeting on "Algebraic curves - introduction"*, India, February-March 2014.

2. *AIS combinatorics (2014)*, India, April-May 2014.

Senthil Kumar K

Research Summary:

1. Liouville Numbers and Schanuel's Conjecture (This is a joint work with R. Thangadurai and M. Waldschmidt). There are two parts in this work. In the first part, using Baire's Theorem (*In a complete or locally compact space X, any G_δ-subset is dense*), we deduce some consequences related with Liouville numbers. In the second part, using the properties of analytic functions and again by the use of Baire's Theorem, we prove the following result, which is a partial result towards Schanuel's Conjecture: *Let $n \geq 1$ and $1 \leq m \leq n$ be given integers. Then there exist uncountably many n-tuples $(\alpha_1, \ldots, \alpha_n) \in \mathbf{L}^n$ such that $\alpha_1, \ldots, \alpha_n$ are linearly independent over $\mathbb{Q}$, $e^{\alpha_i} \in \mathbf{L}$ for all $i = 1, 2, \ldots, n$ and*

$$\mathrm{trdeg}_{\mathbb{Q}}\mathbb{Q}(\alpha_1, \ldots, \alpha_n, e^{\alpha_1}, \ldots, e^{\alpha_n}) = n + m.$$

Here $\mathbf{L}$ denotes the set of Liouville numbers, and $\mathrm{trdeg}_{\mathbb{Q}}K$ denotes the transcendence degree of the field extension K of $\mathbb{Q}$.

2. Fields of Mahler's U-numbers. 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. The U-numbers are further divided into classes of type U_m-numbers ($m \in \mathbb{N}$). In this work, we study the image of a U-number under power series. We also study numbers which are algebraic over fields which can be obtained by adjoining U-numbers to number fields. Further, we shall give a

another proof that the sets U_m are non empty (which was first confirmed by W. J. LeVeque).

3. Multiple Zeta Values. In this work, we classify all the convergent sequences of multiple zeta values which do not converge to 0. Using this classification, we completely describe the iterated derived sets of the set of multiple zeta values in $\mathbb{R}$. Our results imply that the set of multiple zeta values, ordered by $\geq$, is a well-ordered set. We determine its type of order, which is ω^3, where ω is the smallest infinite ordinal.

Publications:

1. K. Senthil Kumar, R. Thangadurai and M. Waldschmidt, *Liouville numbers and Schanuel's conjecture,* Arch. Math. **102**, 59–70, (2014)

2. K. Senthil Kumar, R. Thangadurai and M. Waldschmidt, *Liouville numbers, Liouville sets and Liouville fields*, To appear in Proc. Amer. Math. Soc.

Preprints:

1. K. Senthil Kumar, *Fields of Mahler's U-numbers,* (Communicated).

2. K. Senthil Kumar, *Order Structure and topological properties of the set of multiple zeta values,* (Communicated).

Conference/Workshops Attended:

1. *CIMPA-ICTP Research School on Algebraic Curves over finite fields and applications*, Philippines, July, 2013.

2. *CMI IMSC Joint Conference on Analytic Theory of Automorphic Forms*, India, December, 2013.

Other Activities:

1. I gave a Lecture on Algebraic Sets (First Chapter of Fulton's Algebraic Curves book) in Discussion Meeting II on Algebraic Curves, Feb 19 – Mar 5, 2014 at Harish-Chandra Research Institute, Allahabad, India.

Balesh kumar

Research Summary:

I am studying algebraic number theory. Basically I am trying to understand the Chebotarev density theorem and its various application in number theory, which is a for-reaching generalisation of Dirichlet's theorem of primes in arithmetic progression. Also, I am studying certain $L-$series namely Dirichlet's $L-$series and its analytic properties together with its deep generalisation to Artin $L-$series. Also, I am studying basics of Hilbert modular forms and trying to understand the modular form and its properties associated to number fields.

Preprints:

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

Conference/Workshops Attended:

1. *Advanced Instructional Schools on Analytic number theory, 10-30 june 2013, KIIT Bhubaneswar, India.*

2. *Discussion meeting on algebraic curves-2, 19-5 march 2014, HRI Allahabad, India.*

Visits to other Institutes:

1. Kerala School of Mathematics, 10-27 march 2014, Kerala, India.

Other Activities:

1. Tutor for Discussion meeting on algebraic curves-2, 19-5 march 2014, HRI Allahabad, India.

Bibekananda Maji

Research Summary:

I am working on finding the number fields generated by 4-torsion(and subsequently for n-torsion) points of an elliptic curve and the corresponding Galois groups using elementary group theory, class field theory and arithmetic of elliptic curve. Some cases have already been worked out..

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

Conference/Workshops Attended:

1. *AIS-Combinatorics* at HRI, India, Apr 28- May 17, 2014.
2. *Discussion Meeting on Algebraic Curves* at HRI, India, Feb 19 - March 5, 2014
3. *Conference on Analytic Theory of Automorphic Forms* at IMSc, Chenai, India, Dec 9 - 13, 2013
4. *AIS- Analytic Number Theory* at KIIT, Bhubaneswar, India, June 10 - 30, 2013.

Preprints:

1. Bibekananda Maji, *Number Field generated by 4-torsion points of an elliptic curves.*
2. Bibeakananda Maji, *On the infinitude of primes.*

Other Activities:

1. Tutor for Geometry and Topology in Summer programme in Mathematics(SPIM) at HRI Allahabad, June-July 2013.

Ramesh Manna

Research Summary:

In the past one year I have been studying local smoothing estimates for the Fourier integral operator of the form

$$\mathcal{F}f(x,t) = \int e^{i<x,\xi>} e^{it|\xi|} a(x,t,\xi)\hat{f}(\xi)d\xi \tag{1}$$

where $a \in C^\infty(\mathbb{R}^n \times \mathbb{R} \times (\mathbb{R}^n \setminus 0)$ is assumed to be homogeneous of degree zero in ξ and which vanishes for (x,t) outside fixed compact sets.
Boundedness of this Fourier integral operators on L^p is being studied. The previous results was obtained by Christopher D. Sogge (1991). It was shown that, for $n = 2$ and $2 < p < \infty$ there is an $\epsilon(p) > 0$ so that

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

We are studying to get the above estimate when $4 \leq p < \infty$ with $\epsilon(p) = \frac{1}{p}$. Proof of the refined estimate of this type involves frequency localization with suitable smooth cut off functions which form a partition of unity, and delicate machinery from Littlewood-Paley theory and the wave front statement.

Conference/Workshops Attended:

1. *Conference on Harmonic Analysis and Operator Theory*, IISER Bhopal, India, 21-23 March 2014.
2. *ATM Workshop Analysis and Geometry*, TIFR-CAM Bangalore, India, 6-10 January 2014.
3. *Real Variable Methods in Harmonic Analysis*, HRI Allahabad, India, 23-30 September 2013.
4. *Advanced Instructional Schools Analysis and Geometry*, TIFR-CAM Bangalore, India, 8-27 July 2013.

Other Activities:

1. Tutor for *Real Analysis* in Summer Programme in Mathematics (SPIM), HRI, Allahabad, June-July 2013.

2. Tutor for *Morse Theory* in Topology and Geometry in Instructional Schools for Lecturers(ATM School) during the period 16^{th} to 28^{th} December 2013, HRI, Allahabad.

Eshita Mazumdar

Research Summary:

My research area is additive combinatorics. In this area I specifically focus on zero-sum problems.Apart from research work, in this academic year I read some papers concerning with this particular field and studied some Ergodic Theory and the Isoperimetric Method. I attended some courses on Algebraic number theory and Algebraic curves.

Conference/Workshops Attended:

1. *Discussion Meeting-II on Algebraic Curves, Harish-Chandra Research Institute, Allahabad, India, February 19- March 5, 2014*

2. *Conference on Analytic Theory of Automorphic forms, Institute of Mathematical Sciences, Chennai, India,December 9-13, 2013.*

Publication

1. Sukumar Das Adhikari and Eshita Mazumdar, Modification of Some Methods in the Study of Zero Sum Constants. *Integers* , 14, paper A 25, (2014).

Jay Gopalbhai Mehta

Research Summary:

1. Quasi-uniqueness of Gaussian prime plus one's:

A subset A of non zero Gaussian integers is said to be a *set of uniqueness* with respect to Gaussian integers if

$$f(A) = \{0\} \implies f \equiv 0$$

for all completely additive functions $f : \mathbb{Z}[i]^* \to \mathbb{C}$.

In 1969, I. Kátai conjectured that the set of rational primes plus one's is a set of uniqueness. This conjecture was completely settled by P.D.T.A. Elliot in 1974. In a joint work with G.K. Viswanadham, we proved that the set of "Gaussian prime plus one's" along with finitely many Gaussian primes of norm up to some constant K is a set of uniqueness with respect to Gaussian integers. This work is going to appear in International Journal of Number Theory.

2. On analytic continuation of multiple zeta functions:
When $r \geq 1$ is an integer, let U_r denote the subset of $\mathbb{C}^r$ consisting of the r-tuples $(s_1, s_2, \ldots, s_r)$ of complex numbers $s_1, \ldots, s_r$ satisfying the conditions

$$\mathrm{Re}(s_1 + \cdots + s_i) > i \qquad \text{for } 1 \leq i \leq r.$$

Then U_r is a convex open subset of $\mathbb{C}^r$ and the *multiple zeta function of depth* r is the complex valued function on U_r defined by the relation

$$\zeta(s_1, \ldots, s_r) = \sum_{n_1 > \cdots > n_r > 0} n_1^{-s_1} \cdots n_r^{-s_r}.$$

In a joint work with Biswajyoti Saha and G.K. Viswanadham, we obtain the meromorphic continuation of multiple zeta functions, together with a complete list of their poles and residues, by means of an elementary and simple *translation formula*. We also express this translation formula in terms of matrices which is a more efficient way for studying poles are residues of multiple zeta functions. We extended our results to certain natural weighted variants of multiple zeta functions. The work is in progress and a draft is being ready.

In a joint work with Debika Banerjee we derived the well-known Wilton's formula for the product of two Riemann zeta functions using the Riesz sum.

Publications:

1. Jay Mehta and G.K. Viswanadham, *Quasi uniqueness of the set of "Gaussian prime plus one's"*, To appear in Internation Journal of Number Theory, Nov., (2014)

Preprints:

1. Jay Mehta, Biswajyoti Saha and G.K. Viswanadham, *On the analytic continuation of mutliple zeta functions*, (in preparation)

2. Debika Banerjee and Jay Mehta, *Linearized product of two Riemann zeta functions*, (in preparation)

Other Activities:

1. Compiled HRI Annual Report for the academic year 2012-2013, May-July 2013.

Akhilesh P.

Research Summary:

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

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

Publications:

1. P. Akhilesh and D.S. Ramana, *A Chromatic Version of Lagrange's Four Squares Theorem* accepted,Monatshefte fur Mathematik ISSN 0026-9255,Monatsh Math,DOI 10.1007/s00605-014-0634-2

Preprints:

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

Conference/Workshops Attended:

1. *AIS Analytic Number Theory* , KIIT Bhubaneswar, june, 2013
2. *Analytic Theory of Automorphic forms* , IMSc, chennai, December, 2013

Visits to other Institutes:

1. I.M.Sc., Chennai, December 23, 2013 to january 7, 2014
2. Kerala School of Mathematics, Kozhikode, january 10 to january 13, 2014
3. Kerala School of Mathematics, Kozhikode, may 20 to june 2, 2014

Other Activities:

1. Tutorial Assitant in Annual Foundation School - Part I (2013),Kerala School Of Mathematics, Kozhikode, December 2013.
2. Tutorial Assitant in Annual Foundation Schools Part II - (2014),Kerala School Of Mathematics, Kozhikode, May 2014.

Pradeep Kumar Rai

Research Summary:

The Bogomolov multiplier $B_0(G)$ of a finite group G is defined as the subgroup of the Schur multiplier consisting of the cohomology classes vanishing after restriction to all abelian subgroups of G. A finite group G is said to be rigid if $|Out_c(G)| = 1$, where $Out_c(G)$ denotes the group of class-preserving outer automorphisms of G. Jointly with Manoj Kumar, we computed $|Out_c(G)|$ for all p-groups G of order p^6, where p is an odd prime. As an application, we provide an affirmative answer to the following question of Kang and Kunyavskiĭ for all group of order p^6: Is it true that $B_0(G) = 0$ for all rigid group?

Preprints:

1. Pradeep K. Rai and Manoj K. Yadav, *On rigidity of groups of order p^6*, Preprint

Conference/Workshops Attended:

1. *Discussion Meeting on Group Theory*, India, May 2014.
2. *Ischia Group Theory Conference*, Naples, Italy, April 2014.
3. *Instructional School of Schur Multiplier and Related Topics*, India, March 2014.

Invited Lectures/Seminars:

1. *Class-preserving automorphisms of groups*, Discussion Meeting on Group Theory, IISER Mohali, Mohali, May 2014.

Other Activities:

1. Presented a poster "On Automorphisms of Groups" at Ischia Group Theory Conference 2014, Naples, Italy, April 2014.
2. Organised "Instructional School on Schur Multiplier and Related Topics" at HRI, March 01 - 08, 2014 (jointly with Manoj Kumar and Vipul Kakkar).

Rahul Kumar Singh

Research Summary:

During last one year I have been working on a problem which is about interpolation of minimal surfaces between two given real analytic closed curves say a and b. We insert closed curves $l_1, l_2, \cdots, l_m$ at specific locations and proved that there exists piecewise minimal surfaces of the Bjorling-Schwartz type interpolating between a to l_1, l_2 to $l_3, \cdots, l_m$ to b.This is joint work with my supervisor Dr. Rukmini Dey and Pradip Kumar.
I have also been studying the question of classifying constant mean curvature(CMC) surfaces that are algebraic.We say that a surface in $\mathbb{R}^3$ is algebraic if it is locally given by zeroes set of some polynomial. It is already known that of regular CMC surfaces, only the sphere, cylinder and plane are algebraic.We are studying non-regular CMC surfaces and have made progress on this question amongst the class of rotational and helicoidal CMC surfces.This is joint work with my supervisor.

Conference/Workshops Attended:

1. *ATM Workshop Analysis and Geometry*, TIFR-CAM Bangalore, India, January, 2014.

2. *Advanced Instructional School Analysis and Geometry*, TIFR-CAM Bangalore, India, July 2013.

Sneh Bala Sinha

Research Summary:

For a natural numbers a and q with $(a, q) = 1$ and for a finite set of primes Ω not containing any prime factors of q, we define the generalized Euler Lehmer constants by

$$\gamma(\Omega, a, q) := \lim_{x\to\infty} \left(\sum_{\substack{n\leq x \\ n\equiv a(mod q)}} \frac{1_\Omega(n)}{n} - \delta_\Omega \frac{\log x}{q} \right)$$

and

$$\delta(\Omega, a, q) := \lim_{x\to\infty} \frac{1}{x} \left(\sum_{\substack{n\leq x \\ n\equiv a(mod q)}} 1_\Omega(n) \right)$$

where,

$$\delta_\Omega := \lim_{x\to\infty} \frac{1}{x} \sum_{n\leq x} 1_\Omega(n),$$

and

$$1_\Omega(n) := \begin{cases} 1 & \text{if } (n, \prod_{p\in\Omega} p) = 1, \\ 0 & \text{otherwise} \end{cases}$$

We show that members of this infinite family of numbers are transcendental with atmost one exception.

Preprints:

1. Sanoli Gun, Ekata Saha and Sneh Bala Sinha, *Transcendence of Generalized Euler- Lehmer Constants.*

Conference/Workshops Attended:

1. Fourier analysis of groups in combinatorics, November 18-30, 2013, North Eastern Hill University, Shillong, India .
2. Ram Murty conference, 9-13 December 2013, IMSc, Chennai, India.
3. A discussion meeting on 'Algebraic curves - introduction' from 19th February to 05th March, 2014, HRI, Allahabad, India.
4. AIS combinatorics (2014), 28th April -17th May, HRI,Allahabad, India.

Visits to other Institutes:

1. IMSc, Chennai, India during 15th July to 15 September 2013.

Invited Lectures/Seminars:

1. Poster presentation at IMSc, Chennai.

Kuntal Banerjee

Research Summary:

1. For a family $(F_{t,a} : x \mapsto x + t + a\phi(x))$ of increasing homeomorphisms of $\mathbb{R}$ with ϕ being Lipschitz continuous of period 1, there is a parameter space consisting of the values (t, a) such that the map $F_{t,a}$ is strictly increasing and it induces an orientation preserving circle homeomorphism. For each $\theta \in \mathbb{R}$ there is an Arnol'd tongue $\mathcal{T}_\theta$ of translation number θ in the parameter space. Given a rational p/q, it is shown that the boundary $\partial\mathcal{T}_{p/q}$ is a union of two Lipschitz curves which intersect at $a = 0$ and there can be a non zero angle between them. In this direction we compute the first order asymptotic expansion of the boundaries of the rational and irrational tongues in the parameter space around $a = 0$.

For the standard family $(S_{t,a} : x \mapsto x + t + a\sin(2\pi x))$, the boundary curves of $\mathcal{T}_{p/q}$ have the same tangency at $a = 0$ for $q \geq 2$ and it is known that q is their order of contact. Using the techniques of guided and admissible family, we give a new proof of this. In particular we relate this to the parabolic multiplicity of the map $s_{p/q} : z \mapsto e^{i2\pi p/q} z e^{\pi z}$ at 0. A characterization of analytic and guided family of circle diffeomorphisms is also obtained.

2. It is interesting to study the properties and results of Siegel disks which are still valid for Herman rings, since both are rotation domains. One small step in this direction is to study Jellouli's result where he studied the perturbations of a linearizable map with a Siegel disk at its fixed point. He has an estimate which shows that if the perturbed maps are not far from the linearizable map then the linearization equation is valid with an error term for the perturbed map. The same thing holds when we look at the perturbation of a linearizable map which has a Herman ring. This is an ongoing project.

Preprints:

1. Kuntal Banerjee, *Boundaries of the Arnold tongues and the standard family,* arXiv:1402.4756

2. Kuntal Banerjee, *Jellouli's lemma for Herman ring*, (in preparation)

Visits to other Institutes:

1. Indian Institute of Science Education and Research Mohali, Mohali, India, November 2013,
2. Chennai Mathematical Institute, Chennai, India, January 2014,
3. Ramakrishna Mission Vivekananda University, Belurmath, India, February 2014.

Invited Lectures/Seminars:

1. *Arnol'd tongues and Circle homemorphisms*, Departmental Seminar, Indian Institute of Science Education and Research, Mohali, November 2013.
2. *On the boundaries of the Arnol'd tongues*, CMI Seminar, Chennai Mathematical Institute, Chennai, January 2014.

Other Activities:

- Delivered a series of eight lectures on the 'Dynamics of Circle Homeomorphisms' at the Instructional School for Lecturers, held at HRI during December 16-28, 2013.
- Acted as a referee for Contemporary Mathematics Series of American Mathematical Society.

Vipul Kakkar

Research Summary:

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

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

During the academic year "2013-2014", we (jointly with Dr Vivek Kumar Jain, preprint available at arxiv.org/abs/1402.3378) have described the notion of solvable and nilpotent right transversals. It is shown that if S is solvable or nilpotent, then the group $G_S S$ is solvable. Also, we (jointly with Laxmi Kant Mishra, preprint avialable at http://arxiv.org/abs/1402.1002) define a new graph $\Gamma_d(G)$ on a finite group G, where d is a divisor of $|G|$. The vertices of $\Gamma_d(G)$ are the subgroups of G of order d and two subgroups H_1 and H_2 of G are said to be adjacent if there exists $S_i \in T(G, H_i)$ $(i = 1, 2)$ such that $S1 \cong S2$. We have discussed the completeness of $\Gamma_d(G)$ for various groups like finite abelian groups, dihedral groups and some finite p-groups.

Preprints:

1. Vivek Kumar Jain and Vipul Kakkar, *Solvable and Nilpotent Right Loops* http://arxiv.org/abs/1402.3378

2. Vipul Kakkar and Laxmi Kant Mishra, *On Transiso Graph* http://arxiv.org/abs/1402.1002

3. Vipul Kakkar *An Example of a Right Loop Admitting Only Discrete Topolization* http://arxiv.org/abs/1308.4500

Conference/Workshops Attended:

1. *Instructional School on Schur Multiplier and Related Topics*, Harish-Chandra Research Institute, Allahabad, India, March 2014.

2. *Discussion Meeting on Group Theory*, IISER Mohali, India, May 2014.

Invited Lectures/Seminars:

1. *On the Congruences in Right Loops*, Discussion Meeting on Group Theory, IISER Mohali, Mohali, India, May 2014.

Other Activities:

1. I was a tutor in the workshop "Instructional School on Schur Multiplier and Related Topics" at Harish-Chandra Research Institute, Allahabad, India, March 2014

2. I have taken the tutorials in the course "Schur Multiplier" for the students of semester II at HRI, Allahabad .

Bhavin K. Moriya

Research Summary:

During my stay, I have been working on Zero Sum Problems with Prof. S. D. Adhikari.
Let G be a finite abelian group (written additively). The constant $\eta(G)$ (respectively, $s(G)$) is defined to be the smallest positive integer t such that, any sequence of length t with elements from G contains a non empty zero sum subsequence of length at most $\exp(G)$ (respectively, exactly $\exp(G)$). Let A be a non empty subset of integers, with $0 \notin A$. The constant $\eta_A(G)$ (respectively, $s_A(G)$) is defined to be the smallest positive integer t such that, for any sequence $x_1x_2 \dots x_t$, there exists a subsequence $x_{b_1}x_{b_2} \dots x_{b_s}$ and $a_1, a_2, \dots, a_s$ such that $\sum_{i=1}^{s} a_i x_{b_i} = 0$, with $1 \leq s \leq \exp(G)$ (respectively, $s = \exp(G)$). Whenever, $A = \{1, -1\}$, we are trying to find out these constants for various finite abelian groups and studying relation between them.

Publications:

1. B. K. Moriya, *On weighted zero sum subsequences of short length,* INTEGERS **14**, A21, (2014).

Conference/Workshops Attended:

1. *School on Algebraic Curves*, India, February 2014.

Academic recognition/Awards:

- National Board of Higher Mathematics Grant for attending International Congress of Mathematicians, 2014.

Visits to other Institutes:

1. Kerala School of Mathematics, Calicut, India, December 2013.

Other Activities:

1. Took tutorials for Algebra course at Annual Foundation School - Part I, December, 2013.

2. Took tutorial on Zero Sum Problems in AIS Combinatorics, May, 2014.

Makoto Sakagaito

Research Summary:

The Brauer group plays an important roll in number theory. For example the Brauer group is used to define the reciprocity map of local class field theory and it is known that the Brauer group of projective and smooth surface over finite field determines some special value of Hasse-Weil zeta function if this Brauer group is finite. The Brauer group of regular scheme X is defined by etale cohomology. Moreover for an integer l which is inversible on X we can also express l-torsion part of the Brauer group by etale cohomology and purity theorem for this group, i.e. l-torsion part of the Brauer group of X is the intersection of l-torsion part of the Brauer group of the localazation of X at points of codimension 1 of X, is proved in this point of view. But for an integer p which is not inversible on X we can't express p-torsion part of the Brauer group by etale cohomology and purity theorem for this group is not solved.

During the period November 2013-March 2014, I defined the generalization of the Brauer group (and the character group) by etale motivic cohomology and tried to prove the generalization of results and conjectures on the Brauer group. This research may be related to Kato conjecture on cohomological Hasse principle. This research is proceeding now.

Academic Report - Physics

Jayanta Kumar Bhattacharjee

Research Summary:

In the last few months our work has been primarily on issues in dynamical systems, hydrodynamics and statistical physics.

Over the last twenty years, a new perspective has emerged in dynamical systems where renormalization group ideas are being used to analyze the occurrence of periodic orbits. The implementation of this depends upon the observation that in the course of evolution, the value of a dynamical variable at the present instant is independent of where on the trajectory the initial condition is placed. Traditionally the analysis of periodic orbits has been done by a wide variety of techniques (all perturbation theoretic) where the expansion parameter is carefully chosen or some physically plausible argument is used to remove undesirable terms in perturbation theory. The advantage of the renormalization group is that it provides an unfailing perturbation theory algorithm which works without having to be "clever". However, it has been confined to two dimensional dynamical systems where new results are virtually impossible to find. We have extended the procedure to deal with periodic orbits in higher dimensional dynamical systems provided the orbit lies on a two dimensional surface. This has allowed us to deal with the Hopf bifurcation in the well known Lorenz model and show that there exists a critical value of the Prandtl number which forms the boundary between forward and backward bifurcations. We have also looked at Turing like reaction diffusion systems in the presence of an advective term (imposed electric field if the species are charged, neutral species in a flowing bed etc) and found that a combination of diffusion, drift and finite size effects can lead to a double Hopf bifurcation in such a system.

The field of turbulence from the physicist' point of view is dominated by "Kolmogorovs $5/3$ law". This holds for homogeneous isotropic turbulence where a dimensional analysis based on a physically convincing scenario asserts that the energy spectrum of turbulence $E(k)$ where k is the wave number ($E(k)$ is defined such that its integral over all k gives the volume averaged kinetic energy per unit mass) falls off as the $5/3$ power of k. In convective turbulence on the other hand, which is induced by heating a fluid layer from below in earth's gravity (constant 'g') there is apart from the kinetic energy, an energy due to thermal fluctuations. If this dominates then the exponent $5/3$ is supposed to change to $11/5$. This has never been seen in any experimental or numerical work so far. Examining the Kol-

mogorov type physical arguments for convective turbulence, we found that it is inevitable that corrections to scaling will be present and hence finding pure scaling in convective turbulence would be well nigh impossible. In another contribution in the area of hydrodynamics we have seen that an analogue of the hydraulic jump seen in kitchen sinks can exist in a fast flowing nuclear fluid (quark gluon plasma e.g.) produced when two heavy nuclei collide leading to a fast flow of nuclear matter in the transverse plane. We claim that the abrupt change in the velocity profile is the analogue of the jump.

In the area of statistical physics we have studied the concentration fluctuations near the micelle formation thresholds and calculated the excess specific heat arising from the fluctuations. This excess specific heat shows up in the variation of the sound speed with concentration near the threshold. Extending the study to dynamical phenomena we have shown that the specific heat will become complex near the threshold and this will lead to excess sound attenuation. The qualitative features exist in data that can be found in literature. A real quantitative comparison will require careful experimental determination of relaxation rates.

Publications:

1. J K Bhattacharjee and U Kaatze, Fluctuations near the critical micelle concentration I. Premicellar aggregation,relaxation rate and isentropic compressibility, J.Phys Chem **B117** 3790(2013)

2. J K Bhattacharjee and U Kaatze,Fluctuations near the critical micelle concentration II.Ultrasonic attenuation and spectrum, J. Phys Chem **B117** 3798 (2013)

3. B Agarwalla,S Galhotra and J K Bhattacharjee,Diffusion driven instability to a drift driven one : Turing patterns in the presence of an electric field, J Math Chem DOI **10.1007/S10910-013-0254-4** (2013)

4. S Galhotra, J K Bhattacharjee and B Agarwalla, Turing -Hopf instabilities through a combination of diffusion, advection and drift, J Phys Chem **140** 024501 (2014)

5. N Sarkar,A Basu, J K Bhattacharjee and A K Ray,Acoustic horizons in steady spherically symmetric nuclear fluid flows, Phys Rev **C88** 055025 (2013)

6. H Pharasi,K Kumar and J K Bhattacharjee,Entropy and energy spectra in low prandtl number convection with rotation, Phys Rev **E89** 023009 (2014)

7. D Das, D Banerjee and J K Bhattacharjee,Supercritical and subcritical Hopf bifurcations in two and three dimensions, Nonlinear Dynamics DOI **10.1007/s11071-014-1282-8** (2014)

Invited Lectures/Seminars:

1. "Lectures on Nonlinear Dynamics" Homi Bhabha Centre for Science Education NIUS program June 5th and 6th (2013)

2. "Extremum Principles" NASI summer school inaugural lecture June 17th (2013)

3. "Lectures on Nonlinear Dynamics" Advanced School in Nonlinear Dynamics, Calcutta University, Department of Applied Mathematics Sept 23rd-Sept 26th (2013)

4. "Scales and scaling in turbulent convection" TIFR (Hyderabad) Nov 21st (2013)

5. "Scales and scaling in turbulent convection" JNCASR Nov 26th (2013)

6. "Turbulent Convection" Intl Conf on Non-linear Dynamics, IIT Indore 11th Dec (2013)

7. "Convergent story of a divergent viscosity" National Conference on Nonlinear Dynamics and Statistical Physics, IACS Kolkata Jan 2 (2014)

8. "Nonlinear Oscillators : The bridge between physics and mathematics" Keynote address at the conference for the golden jubilee of the mathematics department, Nagpur University Jan 23rd (2014)

9. "In pursuit of a small exponent" S N Bose National Centre Feb 24th (2014)

10. "Patterns in nature" SCOPE talk IIT Kanpur Student Society Feb 28th (2014)

11. "Turbulent Convection" Keynote address in national conference on fluid dynamics and elasticity : Jadavpur University March 6th (2014)

12. "Conservative chaotic systems in classical mechanics and their quantum dynamics" QISCAL 2013 S N Bose National Centre March 21 (2014)

Other Activities:

1. Courses taught in the Integrated PhD program:

2. Classical Electrodynamics Aug Dec 2013, Statistical Mechanics Jan May 2014

Anirban Basu

Research Summary:

The main results of my work are:
Based on the structure of the on-shell linearized superspace of type IIB supergravity, I argue that there is a non–BPS 16 derivative interaction in the effective action of type IIB string theory of the form $(t_8 t_8 R^4)^2$, which I call the R^8 interaction. Using the KLT relation, I analyse the structure of the tree level eight graviton scattering amplitude in the type IIB theory, which leads to the R^8 interaction at the linearized level. This involves an analysis of color ordered multi-gluon disc amplitudes in the type I theory, which shows an intricate pole structure and transcendentality consistent with various other interactions. Considerations of S-duality show that the R^8 interaction receives non-analytic contributions in the string coupling at one and two loops. Apart from receiving perturbative contributions, I show that the R^8 interaction receives a non-vanishing contribution in the one D-instanton-anti-instanton background at leading order in the weak coupling expansion.

I consider purely gravitational interactions of the type $D^{6n}R^4$ in the effective action of M theory which are related to the type IIA interactions of the form $e^{2n\phi_A} D^{6n} R^4$ where ϕ_A is the type IIA dilaton. The coefficients of the M theory interactions are determined by the strongly coupled type IIA theory. Given the nature of the dilaton dependence, it is plausible that for low values of n, the coefficient has a similar structure as the genus $(n+1)$ string amplitude of the type IIA $D^{6n}R^4$ interaction, namely the transcendental nature. Assuming this, and focussing on the even–even spin structure part of the type IIA string amplitude, this coefficient is given by the

type IIB genus $(n+1)$ amplitude, which I constrain using supersymmetry, S–duality and maximal supergravity. The source terms of the Poisson equations satisfied by the S–duality invariant IIB couplings play a central role in the analysis. This procedure yields partial contributions to several multi–loop type IIB string amplitudes, from which I extract the transcendental nature of the corresponding M theory couplings. For $n \leq 2$, all possible source terms involve only BPS couplings. While the R^4 and D^6R^4 M theory couplings agree with known results, the coefficient of the $D^{12}R^4$ interaction takes the form $\zeta(2)^3(\Omega_1 + \Omega_2\zeta(3))$. I also analyze the $D^{18}R^4$ and $D^{24}R^4$ interactions, and show that their coefficients have at least the terms $\zeta(2)^4(\tilde{\Omega}_1 + \tilde{\Omega}_2\zeta(3) + \tilde{\Omega}_3\zeta(5))$ and $\zeta(2)^5(\underline{\Omega}_1 + \underline{\Omega}_2\zeta(3) + \underline{\Omega}_3\zeta(5) + \underline{\Omega}_4\zeta(3)^2 + \underline{\Omega}_5\zeta(7) + \underline{\Omega}_6\zeta(3)\zeta(5) + \underline{\Omega}_7\zeta(3)^3)$ respectively. The various undetermined constants have vanishing transcendentality.

Publications:

1. Anirban Basu, *The structure of the R^8 term in type IIB string theory,* Class.Quant.Grav. **30**, 235028, (2013)

Preprints:

1. Anirban Basu, *The structure of the R^8 term in type IIB string theory,* arXiv:1306.2501

2. Anirban Basu, *Constraining gravitational interactions in the M theory effective action,* arXiv:1308.2564

Conference/Workshops Attended:

1. *National Strings Meeting*, IIT Kharagpur, December, 2013.

2. *Modern Developments in M-theory*, Banff Canada, January 2014.

Visits to other Institutes:

1. Saha Institute of Nuclear Physics, Kolkata, India, January 2014.

Invited Lectures/Seminars:

1. *Higher Derivative Corrections in String Theory*, National Strings Meeting, IIT Kharagpur, December 2013.

2. *Constraining gravitational interactions in the M theory effective action*, Saha Institute of Nuclear Physics, Kolkata, January 2014.

3. *Constraining gravitational interactions in the M theory effective action*, Modern Developments in M-theory, BIRS Canada, Canada, January 2014.

Other Activities:

1. Tutor for the Quantum Field Theory course in the preparatory SERC school, Tezpur University Assam, June, 2013.

2. Taught Quantum Field Theory in the Refreshers' Course, Silchar University, Assam, December, 2013.

Tapas Kumar Das

Research Summary:

In the last one year, I have been working on the stability properties of the general relativistic axisymmetric fluid flow in strong gravity from a metric independent approach (in collaboration with my BS-MS dual degree thesis student Deepika B Ananda from IISER Pune, India and with Sourav Bhattacharya, a post doctoral fellow of the astrophysics group, HRI), aspects of analogue gravity phenomena (in collaboration with my former MS thesis student Arpita Chaudhary who is currently working at Thüringer Landessternwarte Tautenburg, Germany, Neven Bilić from Rudjer Bošković Institute, Croatia, Sankhasubhra Nag from Sarojini Naidu College for Women, India, Pratik Tarafdar and Archan S Majumdar from S N Bose National Centre of Basic Sciences, India), study of the anomalous dispersion relation in connection to the Hawking like effects (in collaboration with my former MS thesis student Shamreen Iram from IIT Kanpur, Deepika B Ananda and Sourav Bhattacharya), linear perturbation analysis of quasi-viscous post Newtonian black hole accretion for various geometric configuration of accreting material (in collaboration with my former project student Ishita Maity who is currently working at Louisiana State University, USA, Deepika B Ananda and Sankhasubhra Nag), study of multi-transonic accretion profile under the influence of pseudo-Kerr potentials (in collaboration with Sonali Saga Nag and Sankhasubhra Nag from Sarojini Naidu College for Women, India, Sharmistha Sen from Camellia Institute of Engineering, India and Suparna Roychowdhury from St

Xavier's' College Kolkata, India), phase portrait behaviour of self-gravitating astrophysical flows (in collaboration with my student Satadal Dutta from HRI), analysis of black hole shadow imaging (in collaboration with Madonnlily Lei Huang, Shanghai Astronomical Observatory, China), and on various aspects of the passage of the G2 cloud at the close proximity of SgrA* (in collaboration with Vladimír Karas and Devaki Kunneriath from Academy of Sciences in Czech Republic and Bożena Czerny from Polish Academy of Science).

Publications:

1. Neven Bilić, Arpita Choudhary, Tapas K Das & Sankhasubhra Nag, *The role of axisymmetric flow configuration in the estimation of the analogue surface gravity and related Hawking like temperature,* Classical & Quantum Gravity **31**, Issue 3, article id. 035002, (2014)

Preprints:

1. Deepika B Ananda, Sourav Bhattacharya & Tapas K Das *Acoustic geometry through perturbation of accretion rate : I - radial flow in static spacetime,* arXiv:1406.4262 [astro-ph.HE]

2. Deepika B Ananda, Sourav Bhattacharya & Tapas K Das *On the realizability of relativistic acoustic geometry under a generalized perturbation scheme for axi-symmetric matter flow onto black holes* , arXiv:1406.3697 [astro-ph.HE]

3. Sankhasubhra Nag, Deepika B Ananda, Ishita Maity & Tapas K. Das, *Development of Secular Instability in Different Disc Models of Black Hole Accretion,* arXiv:1406.3707 [astro-ph.HE]

Other Activities:

1. Mentoring students
   (a) MS Shamreen Iram from IIT Kanpur (May - July & November - December 2013).
   (b) MS Indrani Nilima from ISM Dhanbad (May - July & November - December 2013).
2. Thesis Examination

(a) Served as the examiner of a Ph.D. thesis (submitted to Calcutta University) on black hole thermodynamics.

AseshKrishna Datta

Research Summary:

In continuation of our immediately preceding work on the phenomenology of a non-minimal Universal Extra Dimension (nmUED) where we started a systematic study of the scenario *for the first time,* I, along with my graduate student and a postdoctoral fellow at HRI, studied in much detail the physics of *Kaluza-Klein (KK) top quarks* in the said framework with an orbifolded (S^1/Z_2) flat extra spatial dimension in the presence of brane-localised terms (BLTs). In general, BLTs affect the masses and the couplings of the KK excitations in a non-trivial way including those for the KK top quarks. On top of that, BLTs also influence the mixing of the top quark chiral states at each KK level and trigger mixings among excitations from different levels with identical KK parity (even or odd). The latter phenomenon of mixing of KK levels is not present in the popular UED scenario known as the minimal UED (mUED) at the tree level. Of particular interest are the mixings among the KK top quarks from level '0' and level '2' (driven by the mass of the Standard Model (SM) top quark). These open up new production modes in the form of single production of a KK top quark and the possibility of its direct decays to Standard Model (SM) particles leading to rather characteristic signals at the colliders. Experimental constraints and the restrictions they impose on the nmUED parameter space are discussed. The scenario is implemented in an event-generator like MadGraph. First ever studies are carried out on the decay patterns of the KK top quarks and their production rates at the LHC. *This work got published in Journal of High Energy Physics.*

In December, 2013 the collaboration expanded to include a senior postdoctoral fellow from abroad. We are since been engaged in understanding the issues in general for broad resonances and the same in the particular context of the nmUED scenario. It is recently recognised that such resonances are of much interest at the early phase of the LHC. However, beyond what is known in the literature, we now realise in our collaboration that quite a few highly involved issues are to be addressed on a priority basis before a robust (and a somewhat general) strategy can be laid down for their search at the LHC. It is found that major improvements are called for on both theoretical and computational/simulation aspects.

Along with my other graduate student, two postdoctoral fellows (one from HRI and one from abroad) and one of my colleagues from HRI, I have also been engaged in studies within the framework of the so-called Next to Minimal Supersymmetric Model (NMSSM). Of recent, some aspects of this scenario have received special attention in light of the current data from the LHC on the properties of the Higgs boson and our study focusses on these.

In a different collaboration with one of my colleagues from another institute and a graduate student, I am studying phenomenological implications of a supersymmetric (SUSY) scenario where lepton number is promoted to an (approximate) $U(1)_R$ symmetry. Such a scenario is characterised by the presence of Dirac gauginos and the viability of large vacuum expectation values for the sneutrinos. These have been shown to have drastic ramification for SUSY searches at the LHC. We study such a scenario by minimally extending the same with a right-handed neutrino superfield which now provides a very light neutralino ($\sim$ a few hundred MeV) and a right-handed (sterile) neutrino with mass in keV, suitable for a warm dark-matter candidate. The extended yukawa sector is appearing to have a non-trivial impact on the physics of the Higgs boson which is now being studied in the light of available results from the LHC experiments.

Publications:

1. Aseshkrishna Datta, Kenji Nishiwaki, Saurabh Niyogi, *Non-minimal Universal Extra Dimensions with Brane Local Terms: The Top Quark Sector,* JHEP **1401**, 104, (2014).

Conference/Workshops Attended:

1. *Les Houches Workshop on Physics at TeV Colliders*, France, June, 2013.
2. *Status of Supersymmetry and Dark Matter (SUSY-DM)*, CHEP and Advanced Centre for Applications of QFT, IISc, Bangalore, October, 2013.
3. *Workshop on High Energy Physics Phenomenology (WHEPP)*, Puri, India, December, 2013.

Visits to other Institutes:

1. Theory Division, CERN, Geneva, Switzerland, June, 2013.

2. Tata Institute of Fundamental Research, Mumbai, India, December, 2013.

3. Indian Association for the Cultivation of Science, Kolkata, January, 2014.

Other Activities:

1. Supervising two students for their Ph.D. degree.

2. Supervised reading courses credited by two physics graduate students.

3. Examined a Ph.D. thesis from a reputed institute in India and served as an expert in the panel for the viva-voce examination.

4. Serving as a peer-reviewer for APS and JHEP.

5. Started serving as one of the organisers for the international workshop on *Monte Carlo tools for Physics Beyond the Standard Model (MC4BSM-2014)* held at Daejeon, South Korea.

Aditi Sen De

Research Summary:

Multipartite quantum correlation is an important resource in quantum information protocols and is known to offer significant advantage in quantum tasks in comparison to bipartite ones. In the year 2013-14, we have characterized as well as quantified multisite quantum correlations and found its applications in different physical systems.
We have considered quantum states, with dimer coverings, of an isotropic spin-1/2 lattice. We proved that such spin-1/2 rotationally invariant states are always genuinely multisite entangled, irrespective of the lattice geometry and dimension. We introduced a method to analytically calculate the genuine multipartite entanglement, viz. the generalized geometric measure, of these quantum spin states, with short-ranged dimer coverings, on a square lattice with an arbitrary number of sites. The method enables us to calculate the genuine multisite entanglement for moderately large lattices, and perform finite-size scaling to predict the measure for the infinite two-dimensional square lattice.

In another work, we have established a universal complementarity relation between the capacity of classical information transmission by employing a multiparty quantum state as a multiport quantum channel, and the corresponding genuine multipartite entanglement. We considered the multiport quantum channel for transmitting classical information where a sender wishes to send classical information individually to several receivers by employing the quantum dense coding protocol with a multiparty shared quantum state between all the partners. We found that the quantum advantage in this quantum dense coding scheme is suppressed by the genuine multipartite entanglement of the shared multiparty quantum state. Moreover, we showed that for a given amount of multiparty quantum correlation in any three-qubit pure state, its ability to act as a channel for multiport classical information transmission via quantum states is bounded above by that of a one-parameter class of three-qubit states, which we call the maximally dense coding capable (MDCC) family of states. More precisely, for any three- qubit pure state, with an arbitrarily fixed amount of multiparty quantum correlation, we showed that its quantum advantage in multiport dense coding is always lower than that of the MDCC state with the same amount of the multiparty quantum correlation. We proved the result in the cases when the multiparty measure is the generalized geometric measure or the tangle or the discord monogamy score,

With the experimental groups of A. Kumar, IISc, Bengaluru, and T.S. Mahesh, IISER Pune, we reported a nuclear magnetic resonance experiment, which simulates the quantum transverse Ising spin system in a triangular configuration and further showed that the monogamy of quantum correlations can be used to distinguish between the frustrated and non-frustrated regimes in the ground state of this system. We usee multipartite quantum correlation measures generated by monogamy considerations of negativity, a bipartite entanglement measure, and that of quantum discord, an information-theoretic quantum correlation measure. As expected from theoretical predictions, the experimental data confirmed that the non-frustrated regime has higher multipartite quantum correlations compared to the frustrated one.

Fidelity plays an important role in measuring distances between pairs of quantum states, of single as well as multiparty systems. Based on the concept of fidelity, we introduced a physical quantity, shared purity, for arbitrary pure or mixed quantum states of shared systems of an arbitrary number ofparties in arbitrary dimensions. We found that it is different from quantum correlations. However, we proved that a maximal

shared purity between two parties excludes any shared purity of these parties with a third party, thus ensuring its quantum nature. We further showed that according to the shared purity, W-class states are (relatively) more non-monogamous than the Greenberger-Horne-Zeilinger-class (GHZ-class), among three qubit pure states. Moreover, we applied the measure to quantify properties of the quantum anisotropic XY spin model. We showed that shared purity is also a faithful detector for identifying the phase transition. We obtained the finite-size scaling in this model for shared purity, and found it to be different from that for the entanglement measure called concurrence, and for the information-theoretic quantum correlation measure called quantum discord.

Publications:

1. U. Mishra, A. Sen(De), and U. 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. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Exclusion principle for quantum dense coding,* Phys. Rev. A **87**, 052319 (2013)

3. 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,* Phys. Rev. A **87**, 052318 (2013).

4. K.R.K. Rao, H. Katiyar, T.S. Mahesh, A. Sen(De), U. Sen, and Anil Kumar, *Multipartite quantum correlations reveal frustration in a quantum Ising spin system,* Phys. Rev. A **88**, 022312 (2013)

5. H.S. Dhar, A. Sen(De), and U. Sen, *Characterizing Genuine Multisite Entanglement in Isotropic Spin Lattices,* Phys. Rev. Lett. **111**, 070501 (2013)

6. R. Prabhu, A. Sen(De), and U. Sen, *Genuine multiparty quantum entanglement suppresses multiport classical information transmission,* Phys. Rev. A **88**, 042329 (2013)

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

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

9. R. Prabhu, A. Sen(De), and U. Sen, *Nonergodic classical correlations lead to ergodic quantum correlations in low-dimensional spin models,* Europhys. Lett. **102** 30001 (2013)

10. A. Sen(De) and U. Sen, *Virtual-site correlation mean field approach to criticality in spin systems,* Phys. Lett. A **377**, 1832 (2013)

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

Preprints:

1. M.N. Bera, R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Limit on Time-Energy Uncertainty with Multipartite Entanglement,* arXiv:1303.0706

2. Asutosh Kumar, R. Prabhu, A. Sen(De), and U. Sen, *Do Large Number of Parties Enforce Monogamy in All Quantum Correlations?,* arXiv:1312.6640

3. U. Mishra, A. Sen(De), and U. Sen, *Local Decoherence-free Macroscopic Quantum states,* arXiv:1401.3208

Conference/Workshops Attended:

1. *"International Meet on Quantum Correlations and Logic, Language and Set Theory" at IIT Jodhpur*, India, December 2013.

2. *"International Program on Quantum Information (IPQI)" at IOP, Bhubaneswar*, India, February 2014.

Invited Lectures/Seminars:

1. *Multiparticle Quantum Correlations and its application in Quantum Communication*, UAB Seminar, Universitat Autonoma de Barcelona, Barcelona, Spain, June 2013.

2. *Multisite Quantum Correlations and its application in Quantum Communication*, National Quantum Information Centre, Gdansk, Poland, June 2013.

3. *Quantum Information Perspective of Many-Body Systems*, Meeting on Transport in Topological Insulators, Harish-Chandra Research Institute, Allahabad, India, July 2013.

4. *Recent Trends on Quantum Comunication*, NCRA Colloquium, National Centre for Radio Astrophysics, Pune, India, July 2013.

5. *Quantum Communication*, Workshop on Theoretical Physics, Srinivasa Ramanujan Institute for Basic Science (SRIBS), Pampady, Thiruvananthapuram, India, August, 2013.

6. *Multiparticle Quantum Correlations and its application in Quantum Communication*, International Meet on Quantum Correlations and Logic, Language and Set Theory, Indian Institute of Technology Jodhpur, India, December 2013.

7. Interaction session with students, Indian Institute of Technology - Benaras Hindu University, Varanasi, India, February 2014.

8. *Quantum Communication (2 Lectures)* and *Monogamy of Quantum Correlations*, in International Program on Quantum Information (IPQI), Institute of Physics, Bhubaneswar, India, February 2014. [pdf available on program website.]

Visits to other Institutes:

1. ICFO-The Institute of Photonic Sciences, Barcelona, Spain, June 2013.

2. Universitat Autonoma de Barcelona, Spain, June 2013.

3. University of Gdansk, Poland, June 2013.

4. National Quantum Information Centre in Gdansk, Poland, June 2013.

5. National Centre for Radio Astrophysics, Pune, India, July 2013.

6. Indian Institute of Science Education and Research (IISER-Pune), India, July 2013.

7. Srinivasa Ramanujan Institute of Basic Sciences, Thiruvananthapuram, India, August 2013.

8. Indian Institute of Technology Jodhpur, India, December 2013.

9. Department of Physics, Indian Institute of Technology - Benaras Hindu University, Varanasi, India, February 2014.

10. Institute of Physics, Bhubaneswar, February 2014.

Academic recognition/Awards:

- Buti Foundation Award from Indian Physics Association, 2014.

Other Activities:

1. Taught a one-semester course on "Quantum Information and Computation" during Aug-Dec 2013.

2. Guiding the theses of Tamoghna Das, Debasis Sadhukhan of HRI and Himadri S Dhar from JNU.

3. Guided projects of the following HRI graduate students:

   (a) Debasis Sadhukhan, on "Quantum Disordered System" (Summer 2013).

   (b) Debasis Sadhukhan, on "Behavior of Quantum Correlations in Quantum Disordered System" (Aug-Dec 2013).

   (c) Debasis Sadhukhan on "Quantum Correlation Length" (Jan-May 2014).

   (d) Tamoghna Das, on "Multipartite Dense Coding vs. Quantum Correlation" (Jan-May 2014).

   (e) Titas Chanda, on "Quantum Biology" (Aug-Dec 2014).

   (f) Titas Chanda on "Robustness of quantum correlations in the prsence of noise" (Jan-May 2014).

4. Organized a collaborative meeting on "Quantum Information Processing and Applications (QIPA-2013)" held at HRI in December 2013, with 61 speakers and 64 other participants. The other organizers were R. Prabhu, Arun K. Pati, and Ujjwal Sen of HRI. [www.hri.res.in/~qipa13/]

5. Guiding the project work of a student, Sumanth Kumar, National Institute of Technology, Calicut, and Kunal Sharma, IISER Bhopal, May-July 2013.

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

7. Serving as referees in national and international journals.

8. Serving as members of the PhD committees of Avijit Misra, Utkarsh Mishra, Debasis Mondol, Nayabanta Swain, Avinanda Chaudhuri, Akansha Singh, and Swapnamay Mondal.

Raj Gandhi

Research Summary:

Detailed and extensive studies of the physics related to the Long Baseline Neutrino Experiment (LBNE) were completed. They included the determination of the mass hierarchy and CP violation. A study of the capability of the ICAL-INO to Lorentz and CPT violation was also done. Ongoing work on the consequences of the CPT theorem and Unitarity for the baryon asymmetry, related to the Nanopoulos-Weinberg theorem was completed. Studies on non-standard interactions beyond the Standard Model and the ultra-high energy events seen at IceCube and their relation to dark matter are in progress.

Publications:

1. V. Barger, A. Bhattacharya, A. Chatterjee, R. Gandhi, D. Marfatia and M. Masud, *Configuring the Long-Baseline Neutrino Experiment* Phys. Rev. D **89**, 011302 (2014) [arXiv:1307.2519 [hep-ph]].

2. A. Bhattacharya, R. Gandhi and S. Mukhopadhyay, *Re-analysing the implications of CPT and unitarity for baryogenesis and leptogenesis* Phys. Rev D, to appear. arXiv:1109.1832 [hep-ph].

3. K. Bora, D. P. Roy, R. Gandhi, D. K. Chodhury, N. N. Singh, N. Sinha, M. P. Bora and A. A. Sen, *Proceedings, National Conference on Contemporary Issues in High Energy Physics and Cosmology (NC-HEPC 2013) : Gauhati, India, February 12-14, 2013* J. Phys. Conf. Ser. **481** (2014).

Preprints:

1. A. Chatterjee, R. Gandhi and J. Singh, *Probing Lorentz and CPT Violation in a Magnetized Iron Detector using Atmospheric Neutrinos* arXiv:1402.6265 [hep-ph].

2. C. Adams *et al.* [LBNE Collaboration], *The Long-Baseline Neutrino Experiment: Exploring Fundamental Symmetries of the Universe* arXiv:1307.7335 [hep-ex].

3. C. Adams *et al.* [LBNE Collaboration], *Scientific Opportunities with the Long-Baseline Neutrino Experiment* FERMILAB-CONF-13-300.

4. A. Chatterjee, M. K. K., K. Rawat, T. Thakore, V. Bhatnagar, R. Gandhi, D. Indumathi and N. K. Mondal *et al.*, *A Simulations Study of the Muon Response of the Iron Calorimeter Detector at the India-based Neutrino Observatory* arXiv:1405.7243.

Conference/Workshops Attended:

1. *Fermilab User's meeting*, Chicago, USA, June 2013,e.g. January, 2011

2. *LBNE Collaboration Meeting*, Chicago, USA, June 2013,

3. *INO Collaboration Meeting*, Madurai, September 2013,

4. *LBNE-India Meeting*, Mumbai, November 2013,

5. WHEPP, Puri, December 2013

Visits to other Institutes:

1. University of Wisconsin, Madison, USA, May-June 2013,

2. Fermilab, Chicago , USA, June 2014.

Invited Lectures/Seminars:

1. *Physics Possibilities with the LBNE Near Detector*, Invited Talk, LBNE meeting , BARC, November 2013.

2. *Physics of Ultra-High Energy Neutrinos*, Invited Talk, WHEPP, Puri, December 2013.

Academic recognition/Awards:

- Fermilab Intensity Frontier Fellow, 2014

Other Activities:

1. I am a member of the LBNE and INO Collaborations, and jointly leading (with Brajesh Choudhary) the Indo-US collaboration on Neutrino Physics. I presently have three graduate students, Animesh Chatterjee, Mehedi Masud and Aritra Gupta working doing their Ph.D under my supevision. I co-taught Advanced Quantum mechanics with Sumathi Rao in Spring 2013.

Rajesh Gopakumar

Research Summary:

The last year has seen further continuation of my research into the duality between higher spin theories in three dimensional anti-de sitter space (AdS_3) and two dimensional conformal field theories (CFT_2). In particular, with Matthias Gaberdiel we have been studying embedding these dualities into string theory. To this end, we studied the case with the largest amount of supersymmetry (SUSY). This is the case of so-called large $\mathcal{N} = 4$ SUSY where we proposed a duality between a particular class of coset CFTs and a corresponding higher spin theory. This involved a new construction of the bulk theory. We hope to use this case to understand better the not very well understood case of string theory on $AdS_3 \times S^3 \times S^3 \times S^1$.

In fact, this construction has actually helped us to relate string theory on the simpler background $AdS_3 \times S^3 \times T^4$ with higher spin theories. We start by considering the above coset theory and its large level limit. It then becomes a free theory - a continuous orbifold. We are able to embed the corresponding dual Vasiliev theory as a subsector of the above AdS string theory. Moreover, this also enables us to reorganise the full partition function of the symmetric product CFT in terms of representations of the higher spin algebra (or rather its W_∞ extension). In particular, the unbroken stringy symmetries of the tensionless limit, as reflected in the extended chiral algebra of the symmetric product CFT, can be characterised by nontrivial W_∞ representations which vastly extend the conventional higher spin symmetry. This direction would be interesting to investigate further to understand the unbroken symmetries of string theory.

With M. Gaberdiel and M. Rangamani, we also completed an investigation of the distribution of the spectrum of states in the bosonic minimal model CFTs. By using a combination of numerical and analytical techniques we studied various regimes and found no evidence for a finite temperature

phase transition. Together with A. Chowdhury, S. Jain, S. Mandal, A. Saha and T. Takimi, we have also been studying the Lagrangian formulation of coset models with an aim to understanding their physics in a more transparent way, especially the role of the light states associated with the holonomies of the gauge field.

Publications:

1. M. Gaberdiel and R. Gopakumar, *Large N=4 Holography*, JHEP **1309**, 036 (2013).

2. M. Gaberdiel, R. Gopakumar and M. Rangamani, *The Spectrum of Light States in Large N Minimal Models*, JHEP **1401**, 116 (2014).

Preprints:

1. M. Gaberdiel and R. Gopakumar, *From Higher Spins to Strings,* (in preparation)

Conference/Workshops Attended:

1. *Conference and Workshop on Higher Spin Theories*, Galileo Galilei Instt., Florence, May 2013.

2. *Seventh Crete Regional Meeting on String Theory*, Kolympari, Greece, Jun. 2013.

3. *GR 20*, Warsaw University, Warsaw, Jul. 2013.

4. *Open questions in an Open Universe*, Bogazici University, Istanbul, Aug. 2013.

5. *Fourth Wits Workshop on Gauge Theory, String theory and Integrability*, Univ. of Witwatersrand, Johannesburg, Sep. 2013.

6. *International Conference on Teichmller theory and interfaces with ergodic theory and group actions*, JNU, New Delhi, Oct. 2013.

7. *National String Meeting*, IIT-Kharagpur, Dec. 2013.

8. *ICTP Spring School on Superstring Theory*, ASICTP, Trieste, Mar. 2013.

Visits to other Institutes:

1. Galileo Galilei Instt., Florence, May 2013.
2. ICTS-TIFR, Bangalore, India, May 2013.
3. Warsaw University, Warsaw, Poland, Jul. 2013.
4. Jagiellonian University, Cracow, Poland, Jul. 2013.
5. Institute for Physics, Czech Academy of Sciences, Prague, Czech Republic, Jul. 2013.
6. Bogazici University, Istanbul, Turkey, Aug. 2013.
7. University of Cape Town, Capetown, S. Africa, Sept. 2013.
8. Univ. of KwaZulu Natal, Durban, S. Africa, Sep. 2013.
9. Univ. of Witwatersrand, Johannesburg, S. Africa, Sep. 2013.
10. JNU, New Delhi, Oct. 2013.
11. IIT-Kanpur, India, Nov. 2013.
12. IIT-Kharagpur, India, Dec. 2013.
13. IISER, Bhopal, India, Feb. 2013.
14. ASICTP, Trieste, Italy, Mar. 2013.

Invited Lectures/Seminars:

1. *Large* $\mathcal{N} = 4$, Conference and Workshop on Higher Spin Theories, Galileo Galilei Instt., Florence, May 2013.
2. *Minimal Model Holography (from Large N to Large* $\mathcal{N}$*)*, Seventh Crete Regional Meeting on String Theory, Kolympari, Greece, Jun. 2013.
3. *Minimal Model Holography*, Two Seminars, Jagiellonian University, Cracow, Poland, Jul. 2013.
4. *Large* $\mathcal{N} = 4$ *Holography*, Seminar, Institute for Physics, Czech Academy of Sciences, Prague, Czech Republic, Jul. 2013.
5. *Minimal Model Holography*, Conference - Open questions in an Open Universe, Bogazici University, Istanbul, Aug. 2013.

6. *String Theory and the Quest for Quantum Spacetime*, Maths. Dept. Colloquium, University of Cape Town, Capetown, S. Africa, Sept. 2013.

7. *Minimal Model Holography*, Seminar, University of Cape Town, Capetown, S. Africa, Sept. 2013.

8. *String Theory and the Quest for Quantum Spacetime*, Maths. Dept. Seminar, Univ. of KwaZulu Natal, Durban, S. Africa, Sep. 2013.

9. *The Simplest Gauge-String Duality?*, International Conference on Teichmller theory and interfaces with ergodic theory and group actions, JNU, New Delhi, Oct. 2013.

10. *AdS/CFT Correspondence and Applications*, Lecture Course at SERC-THEP School, IIT-Kanpur, Nov. 2013.

11. *Large $\mathcal{N} = 4$ Holography*, Review Talk, National String Meeting, IIT-Kharagpur, Dec. 2013.

12. *Minimal Model Holography*, Lecture Course, Asian String Winter School, Puri, Jan. 2014.

13. *String Theory and the Quest for Quantum Spacetime*, Physics Talk, IISER-Bhopal, Feb. 2014.

14. *Higher Spin Gauge Theories*, Two Seminars, IISER-Bhopal, Feb. 2014.

Academic recognition/Awards:

- TWAS Award for the Physical Sciences, 2013
- G. D. Birla Award for Scientific Research, 2013.

Other Activities:

1. Chair of Parallel Session on Strings (and co-organiser of special session on Quantum Mechanics of Black Hole Evaporation), GR20, Warsaw University, 2013

2. Council Member of INSA, 2014.

3. Member, International Advisory Commiittee, String-Math2014, Edmonton, Canada,

4. Member, International Advisory Commiittee, Strings 2014, Princeton, USA.

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

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

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

Anshuman Maharana

Research Summary:

During the period April 2013 to March 2014 my research has focussed on string phenomenology - the endeavour to connect string theory to particle physics and cosmology. There are two key results that we would like to highlight.
The first involved derivation of a consistency condition for flux compactifications. The magnitude of the flux superpotential W_{flux} plays a crucial role in determining the scales of IIB string compactifications after moduli stabilisation. It has been argued that values of $W_{\text{flux}} \ll 1$ are preferred. We have revisited these arguments and found that the consistency condition is actually quite mild: the $W_{\text{flux}} \ll \mathcal{V}^{1/3}$, which can be easily satisfied for $\mathcal{O}(1)$ values of W_{flux}. This regime is also statistically favoured and makes the Bousso-Polchinski mechanism for the vacuum energy hierarchically more efficient.
Secondly, we have constructed an explicit embedding of axionic N-flation in type IIB string compactifications where most of the Kähler moduli are stabilised by perturbative effects, and so are hierarchically heavier than the corresponding $N \gg 1$ axions whose collective dynamics drives inflation. A viable reheating of the Standard Model degrees of freedom can be achieved after the end of inflation due to the perturbative decay of the N light axions which drive inflation.

Publications:

1. M. Cicoli, J. Conlon, Anshuman Maharana, F. Quevedo
A Note on the Magnitude of the Flux Superpotential , JHEP, 1401 (2014)

027

Preprints:

1. Michele Cicoli, Koushik Dutta, Anshuman Maharana, *N-flation with Hierarchically Light Axions in String Compactifications,* 1401.2579

Conference/Workshops Attended:

1. *National Strings Meeting*, India, December 2013

Visits to other Institutes:

1. ICTP, Trieste, Italy, October 2013
2. University of Bologna, Bologna, Italy, October 2013.

Invited Lectures/Seminars:

1. *Overiew of String Phenomenology*, University of Bologna theory seminar, University of Bologna, Bologna, October 2013.
2. *Moduli Stabilisation with N Kahler Moduli*, National Strings Meeting 2013, IIT Kharagpur, Kharagpur, December 2013.

Other Activities:

1. Conference/School Organisation: The 8th Asian Winter School on Strings, Particles and Cosmology (2014), Puri, India.

Pinaki Majumdar

Research Summary:

Our current effort is on developing a real space approach to correlated quantum systems, and applying it to the Mott transition on frustrated lattices, the disorder driven superconductor-insulator transition, confined cold Fermi gases, bosonic matter, *etc*. Specific answers that we have recently obtained include (i) the spontaneous emergence of a glassy phase in some clean but geometrically frustrated Mott systems close to the metal-insulator transition, (ii) the survival of superconducting nanoclusters well above the bulk thermal transition in disordered superconductors, and (iii) the appearance of a novel spectral feature in trapped Fermi superfluids.

Publications:

1. Subrat Kumar Das, Viveka Nand Singh, and Pinaki Majumdar, *Magnon spectrum in the domain ferromagnetic state of antisite-disordered double perovskites,* Phys. Rev. B 88, 214428 (2013).

2. Sanjoy Datta, Viveka Nand Singh, and Pinaki Majumdar, *Radio-frequency spectroscopy of the attractive Hubbard model in a trap,* Phys. Rev. A 89, 053609 (2014).

3. Sabyasachi Tarat and Pinaki Majumdar, *Charge dynamics across the disorder-driven superconductor-insulator transition*, Europhys. Lett., 105 (2014) 67002.

4. Viveka Nand Singh and Pinaki Majumdar, *Huge positive magnetoresistance in antiferromagnetic double perovskite metals*, J. Phys. Cond Mat (in press).

Preprints:

1. Sabyasachi Tarat and Pinaki Majumdar, *A real space auxiliary field approach to the BCS-BEC crossover*, arXiv:1402.0817.

2. Sabyasachi Tarat and Pinaki Majumdar, *Tunneling spectroscopy across the superconductor-insulator thermal transition*, (in preparation).

Conference/Workshops Attended:

1. *MagMA 2013, IIT Guwahati*, India, Dec 2013.

Visits to other Institutes:

1. Tata Institute of Fundamental Research, Mumbai, India, Sep 2013.

Invited Lectures/Seminars:

1. *Mott transition on a frustrated lattice*, MagMA, IIT Guwahati, India, Dec 2013.
2. *Indo-EU scientific collaboration, users perspective*, EU Scientific Cell in India, Varanasi, March 2014.

Other Activities:

1. Organised a School on Cold Atoms at HRI, Feb 2014.
2. Taught the Condensed Matter 2 course.

Biswarup Mukhopadhyaya

Research Summary:

A rigorous study on higher dimensional operators contributing to the coupling of the Higgs boson gauge boson pairs was completed. This included the first and most exhaustive analysis of the response of such operators to LHC cuts as well as various constraints accruing on them from the global analysis of the LHC data (Shankha Banerjee, Satyanarayan Mukhopadhyay, Biswarup Mukhopadhyaya).

The current LHC data on the Higgs bosons can principle accommodate the presence of an additional neutral scalar in the vicinity of mass of the standard model Higgs boson. This possibility was investigated in the context of a geometric scalar, called the radion, in the context of the Randall-Sundrum theoy of warped extra dimensions. The most rigorous limits on radion mass as well as radion-Higgs mixing were obtained (Nishota Desai, Ushoshi Maitra, Biswarup Mukhopadhyaya).

In the Randal Sundrum scenario including higher derivatives of the scalar curvature in the 5-dimensional action, it is possible to have a radion with a relatively small ($\leq$ 1.5 TeV) vacuum expectatiob value, though the first graviton excitation may become much more massive. That this apparently irreconciliable situations are in fact compatoble was demonstreated (Ushoshi Maitra, Soumitra SenGUpta, Biswarup Mukhopadhyaya).

If texture zeros in neutrino mass matrices have to be consistently implemented in a type-II seesaw model, then one requires at least two SU(2) triplet scalars. Some unusual decays of the heavier doubly charged scslars and their implications in LHC experiments were demonstrated (Avinanda Chaushuri, Walter Grimus, Biswarup Mukhopadhyaya).

The supersymmetric inverse seesaw model was re-examined in the light of the recent data on the Higgs boson. The possibility of having invisible decay width for the Higgs boson in such a scenario was investigated, and its LHC implications were pointed out (Shankha Banerjee, P. S. Bhupal Dev, Subhadeep Mandal, Biswarup Mukhopadhyaya, Sourov Roy).

A scenario was investigated, where there are two Higgs doublets, one of which couples to neutrinos alone, and is responsible for Dirac neutrino masses. Some collider as well as cosmological implications of such a model was studied, with special emphasis on the signal of a charged Higgs in this model, which is somewhat elusive in experiments (Ushoshi Maitra, Biswarup Mukhopadhyaya, S. Nandi, Santosh Kumar Rai, Ambresh Shivaji).

A supersymmetric scenario with a right sneutrino dark matter was investigated. In particular, its role in generating the monochromatic photon lines sugegsted in tge Fermi-LAT observation was examined (Arindam Chatterjee, Debottam Das, Biswarup Mukhopadhyaya, Santosh Kumar Rai).

Publications:

1. Avinanda Chaudhuri, Walter Grimus, Biswarup Mukhopadhyaya, *Doubly charged scalar decays in a type II seesaw scenario with two Higgs triplets*, JHEP **1402**, 060, (2014)

2. Biswarup Mukhopadhyaya, Somasri Sen, Soumitra SenGupta, *Matter-Gravity Interaction in a Multiply Warped Braneworld*, J. Phys. **G40**, 015004, (2013)

3. Shankha Banerjee, P. S. Bhupal Dev, Subhadeep Mondal, Biswarup Mukhopadhyaya, Sourov Roy, *Invisible Higgs Decay in a Supersym-*

metric Inverse Seesaw Model with Light Sneutrino Dark Matter, JHEP **1310**, 221, (2013)

4. Nishita Desai, Ushoshi Maitra, Biswarup Mukhopadhyaya, *An updated analysis of radion-higgs mixing in the light of LHC data ,* JHEP **1310**, 093, (2013)

5. Shankha Banerjee, Satyanarayan Mukhopadhyay, Biswarup Mukhopadhyaya, *Higher dimensional operators and LHC Higgs data : the role of modified kinematics,* Phys. Rev. **D89**, 053010, (2014)

6. Ushoshi Maitra, Biswarup Mukhopadhyaya, S. Nandi, Santosh Kumar Rai, Ambresh Shivaji, *Searching for an elusive charged Higgs at the Large Hadron Collider,* Phys. Rev. **D89**, 0555024, (2014)

Preprints:

1. Arindam Chatterjee, Debottam Das, Biswarup Mukhopadhyaya, Santrosh Kumar Rai, *Right Sneutrino Dark Matter and a Monochromatic Photon Line,* e-Print: arXiv:1401.2527 [hep-ph]

2. Ushoshi Maitra, Biswarup Mukhopadhyaya, Soumitra SenGupta *Reconciling small radion vacuum expectation values with massive gravitons in an Einstein-Gauss-Bonnet warped geometry scenario,* e-Print: arXiv:1307.3018 [hep-ph]

Conference/Workshops Attended:

1. *School in High Energy Physics*, Beijing, China, August, 2013.

2. *Symposium in Higgs Physics*, Beijing, China, August, 2013.

3. *Conference on Nuclear and Particle Physics*, Jamia Milia Islamia, Delhi, January, 2014.

4. *Workshop in ELectroweak Symmetry Breaking and Flavour Physics*, Guwahati, India, February, 2014.

5. *Conference on Contemporary Issues in Particple Physics*, Kalyani University, India, March, 2014.

Visits to other Institutes:

1. Indian Institute of Technology, Indore, India, April, 2013.
2. Indian Association for the Cultivation of Science, Kolkata, June-July, 2013, and Decmeber 2013 - January 2014.
3. Institute of High Energy Physics, Academica Sinica, Beijing, China, August, 2013.
4. CERN, Geneva, Switzerland, September - October, 2013.
5. Indian Institute of Technology, Kanpur, November, 2013.

Invited Lectures/Seminars:

1. *The Higgs Boson Saga: Reality and Myth*, Boundary Lecture, Indian Institute of Technology, Indore, April, 2013.
2. *The theory of dark matter direct detection*, A set of pedagogical lectures, Indian Association for the Cultivation of Science, Kolkata, Apri, 2013.
3. *The Ever-Inward Journey*, Colloquium, Regional Computer Centre, Kolkata, June, 2013.
4. *On Higgs Boson and Supersymmetry*, A set of pedagogical lectures, Institute of High Energy Physics, Academica Sinica, Beijing, China, August, 2013.
5. *Scope for New Physics in the Higgs Data*, Invited plenary talk in Symposium on Higgs Physics, Institute of High Energy Physics, Academica Sinica, Beijing, China, August, 2013.
6. *Looking at the Higgs Data: New Physics with and without New Models*, Invited seminar, LAPP, Annecy, France, September, 2013.
7. *Applied Supersymmetry*, Lecture Series in SERC School on Theoretical High ENergy Physics, Indian Institute of Technology, Kanpur, November, 2013.
8. *The Higgs Boson Saga and the God Particle Myth (in Bengali)*, B. B. Ray Memorial Lecture, National Council of Education, Kolkata, January, 2014.

9. *The Higgs Boson and New Physics: the Why's and the How's*, Invited plenary talk, Confenerence on Nuclear and Particle Physics, Jamia Milia Islamia, Delhi, January, 2014.

10. *The Quest for New Physics: Standing on the Shoulder of Higgs Data*, Invited plenary talk, Confenerence on Contemporary Issues in Particle Physics, Kalyani University, West Bengal, March, 2014.

Other Activities:

1. Acted as Co-ordinator, Regional Centre for Accelerator-based Particle Physics, HRI (since 2007).

G. Venketeswara Pai

Research Summary:

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

Preprints:

1. *Magnetic Phase Separation in Orbitally Degenerate Double-exchange Systems*
   with Saurabh Pradhan and Sayan Basak
   (in preparation)

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

3. *Transfer Matrix Approach to Topological Superconductors with Multiple Majorana Modes*
   with Aditya Banerjee
   (in preparation)

Conference/Workshops Attended:

1. *Informal Meeting on Transport in Topological Insulators*
   HRI, Allahabad, July 2013

2. *School and Workshop on Physics of Cold Atoms*
   HRI, Allahabad, February 2014

3. *Visitors Programme 2014*
   Dept. of Physics and Astrophysics, Uni. of Delhi, March 2014

Visits to other Institutes:

1. Dept. of Physics and Astrophysics, Uni. of Delhi, March 2014

2. Dept. of Physics, Sree Kerala Varma College, Thrissur, March 2014

Lectures/Seminars/Short Courses:

1. *Superconductivity in Topological Systems*
   Informal Meeting on Transport in Topological Insulators
   HRI, Allahabad, July 2013
   `Also led the panel discussion on topological superconductivity`

2. A set of lectures on *Bosonic Cold Atoms : from Continuum to Lattice*
   School and Workshop on Physics of Cold Atoms
   HRI, Allahabad, February 2014

3. *Interplay between Correlations and Electron-lattice Coupling in Electronic Systems*
   Visitors Programme 2014, Dept. of Physics and Astrophysics, Uni. of Delhi, March 2014

4. A mini course comprising of 15 lectures on *Phase Transitions and Critical Phenomena*
   Dept. of Physics, Sree Kerala Varma College, March 2014

Other Activities:

1. Guided two visiting project students, Sayan Basak (IIT, Kanpur) during May-July 2013 and December 2013 and C. A. Merin (IIT, Kharagpur) during May-July 2013

2. Taught an advanced graduate course, Quantum Many Body Theory (CMP-III), during January-May 2013

3. Taught a graduate level course, Condensed Matter Physics - I, during August-December 2013

4. Taught a short course on Superfluids, Atom Condensates, and Superconductors, during January-May 2014

5. Co-organised an "Informal Meeting on Transport in Topological Insulators" at HRI, during July 2013

6. Co-organised a "School and Workshop on Physics of Cold Atoms" at HRI, during February 2014

7. Member of the Board of Adjudicators to evaluate thesis for M. S. (Engg.)
   Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore (2013-14)

8. Convener of the Library committee (till May 2013), and a member of the Physics PDF-Visitors' committee and Cluster Computing Facility committee

Tribhuvan Prasad Pareek

Research Summary:

We have developed an exact(non-adiabatic,non-perturbative) density matrix scattering theory for a two component quantum liquid which interacts or scatters off from a generic spin-dependent quantum potential. The generic spin dependent quantum potential[eq.(1)] is a **matrix potential**, hence, adiabaticity criterion is ill-defined. Therefore the full **matrix potential** should be treated non-adiabatically. We succeed in doing so using the notion of **vectorial matrices** which allows us to obtain an exact analytical expression for the scattered density matrix. We find that the number or charge density in scattered fluid,Tr depends on non-trivial quantum interference coefficients, $\mathcal{Q}^{\alpha\beta}_{0ijk}$ which arises due to quantum interference between spin-independent and spin-dependent scattering amplitudes and among spin-dependent scattering amplitudes. The effect of quantum interference coefficients can be studied using a vector $\boldsymbol{Q}^{\alpha\beta}$ defined in terms of $\mathcal{Q}^{\alpha\beta}_{0ijk}$.

The theoretical analysis shows that in presence of spin-dependent interaction the **vector order parameter $\boldsymbol{Q}$** is necessarily non-zero and is related to the commutator and anti-commutator of scattering matrix $\mathcal{S}$ with its dagger $\mathcal{S}^{\dagger}$. It is further shown that $\boldsymbol{Q} \neq 0$, implies four physically equivalent conditions,i.e, **spin-orbital entanglement is non-zero**, **Non-Abelian scattering phase ,i.e, matrices**, scattering matrix is **Non-Unitary** and the broken time reversal symmetry for scattered density matrix. This also implies that quasi particle excitation are anyonic in nature, hence, charge fractionalization is a natural consequence. This aspect has also been discussed from the perspective of number or charge density conservation, which implies i.e, $\mathrm{Tr}(\varrho_{sc}) = \mathrm{Tr}(\varrho_{in})$. On the other hand $\boldsymbol{Q} = 0$ turns out to be a mathematically forced unphysical solution in presence of spin-dependent potential or scattering which is equivalent to **Abelian** hydrodynamics ,**Unitary** scattering matrix, absence of spin-space entanglement, and preserved time reversal symmetry.
The presented theoretical analysis has been formulated using mesoscopic language, where a two terminal mesoscopic systems is connected to spin-dependent scattering region is , which is equivalent to having two potential wells separated by a generic spin-dependent potential barrier. The formulation using mesoscopic language is practically useful because it leads directly to the measured quantities such as conductance and spin-polarization density in the leads, however, the presented formulation is not limited to the mesoscopic system only, its generality has been stressed at various places in or study.
Beside this in the ongoing Indo-French project the French collaborators visited HRI during Dec-2013 for two weeks which was helpful f for our collaboration.

Preprints:

1. Tribhuvan Prasad Pareek *Quantum Non-Abelian Hydrodynamics: Anyonic or Spin-Orbital Entangled liquids, Non-Unitarity of Scattering matrix and Charge Fractionalization* eprint: 1404.2070

2. Trilochan Bagarati, Tribhuvan Prasad Pareek, A. M. Jayannavar*A simple analytical model for coherent charge and spin transport* write (in preparation)

Other Activities:

1. Taught the CMP course to graduate students and other routine adminstrative and academic activities

Arun Kumar Pati

Research Summary:

1. An Epistemic model of Quantum State with Ontic Probability Amplitude:
We first prove that ontological models of the quantum state which are capable of reproducing the Born probability rule and fall in the class of ψ-epistemic models are inconsistent with the Schödinger time evolution. We then model the ontic state space as a complex projective Hilbert space that embeds the projective Hilbert space of quantum mechanics and define a minimalist epistemic state as an average over a set of "hidden states" in the larger space. We show that such a model incorporates probability amplitudes and admits an epistemic interpretation of quantum states. Finally, we prove a second theorem to show that such a model is compatible with locality but ontic models are not.

Weak Values with Remote Postselection and Shared Entanglement: We propose a new protocol for the weak measurement of any observable with remote pre and postselections. We show that if two parties share a pure entangled state, then by using local operations and classical communication they can preselect and postselect at distant locations leading to the weak value of an observable as a shift in the pointer of the apparatus at one location in the process of the weak measurement. This can be achieved with either sharing of a pure maximally or non-maximally entangled state. We generalize the protocol for realizing the weak value of any observable with remote pre and postselection of mixed states. Finally, we show how the weak value is modified in the remote pre and postselection setting if Alice and Bob share a mixed entangled state.

Complementarity of Quantum Correlations in Cloning and Deleting of Quantum State: We quantify the amount of correlation generated between two different output modes in the process of im- perfect cloning and deletion processes. We use three different measures of correlations and study their role in determining the fidelity of the cloning and deletion. We obtain a bound on the total correlation generated in the successive process

of cloning and deleting operations. This displays a new kind of complementary relationship between the quantum correlation required in generating a copy of a quantum state and the amount of correlation required in bringing it back to the original state by deleting and vice versa. Our result shows that better we clone (delete) a state, more difficult it will be to bring the state back to its original form by the process of deleting (cloning).

Weak measurement induced super discord can resurrect lost quantumness: The projective measurement usually destroys the quantum correlation between two subsystems of a composite system, thereby making the measured state useless for any efficient quantum information processing and quantum computation task. The weak measurement acts gently on quantum system and do not force the system state to decoher completely, thus revealing the super quantum discord, which can take value more than that of the normal quantum discord. Remarkably, we prove that the super quantum discord in the post measured state is equal to the difference between the super quantum discord and the normal quantum discord in the original state. Thus, the weak measurement has the ability to resurrect the lost quantumness of any composite quantum state. This suggests a conservation law for the extra quantum correlation in any composite state. The amount of extra quantum correlation which is destroyed by the projective measurement in the original state is equal to the amount of extra quantum correlation captured by the weak measurement in the post-measured state.

Limit on Time-Energy Uncertainty with Multipartite Entanglement: 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 provide examples of physical systems for which the bound reaches close to saturation.

Publications:

1. I. Chakrabarty, A. K. Pati, P. Agrawal, *CTC assisted PR box type correlation can lead to signaling*, Quantum Information and Computation, **14**, 1251 (2014).

2. U. Singh and A. K. Pati, *Quantum Discord with Weak Measurements*, Annals of Phys. **343**, 141 (2014).

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

Preprints:

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

2. D. Mondal and A. K. Pati, *Quantum Speed Limit For Mixed States Using Experimentally Realizable Metric*, arXiv:1403.5182 (2014).

3. A. K. Pati, Partha Ghose, A. K. Rajagopal, *An Epistemic model of Quantum State with Ontic Probability Amplitude*, arXiv:1401.4104 (2014).

4. Sk Sazim, I. Chakrabarty, A. Datta, A. K. Pati, *Complementarity of Quantum Correlations in Cloning and Deleting of Quantum State*, arXiv:1308.4340 (2013).

5. U. Singh, A. K. Pati, *Weak measurement induced super discord can resurrect lost quantumness*, arXiv:1305.4393 (2013).

6. M. N. Bera, R. Prabhu, A. K. Pati, A. Sen De, U. Sen, *Limit on Time-Energy Uncertainty with Multipartite Entanglement*, arXiv:1303.0706 (2013).

Visits to other Institutes:

1. Visited Prof. P. Agrawal, Institute of Physics during July 29 to August 16, 2013.

2. Visited Prof. P. Agrawal, Institute of Physics, Bhubaneswar, during February 6 to March 8, 2014.

Invited Lectures/Seminars:

1. *Nature of Quantum States with Closed Time Like Curves*, Invited speaker in International conference on Quantum Mechanics seen Through Closed-Time Like Curves held at Les-Treilles, France, during June 24-29, 2013.

2. *Weak Measurements and Quantum Correlations*, Invited talk in 79th Annual meeting of the Indian Academy of Sciences during 8-10 November 2013 at Chandigarh, organized by Panjab University in association with CSIR-IMTECH and IISER-Mohali.

Academic recognition/Awards:

- Elected as a Fellow of the National Academy of Science India (NASI), Allahabad, 2013.

Other Activities:

1. In the program committee for 13th Asian Quantum Information Science Conference (AQIS-2013), held at Chenai during August, 2013.
2. Organizer of International Workshop on Quantum Information Processing and Applica- tions (QIPA)-2013 held at HRI, Allahabad during Dec 2-8th, 2013.
3. Organizer of International Program on Quantum Information (IPQI)-2014 held at IOP, Bhubaneswar dring Feb 17-28th, 2014.
4. Guided visiting students in the area of Quantum Information.
5. Evaluated two Ph.D. thesis, one from IISER, Mohali and one from Kolkata University.
6. Guiding four Ph.D. students in the area of Quantum Information from HRI, Allahabad.

Santosh Kumar Rai

Research Summary:

During last year my area of research has been on various new ideas that propose physics beyond the Standard Model (SM) of particle physics. In that spirit, I have been working on models of extended gauge symmetries, Higgs physics and its extensions, supersymmetric theories and their implications in collider experiments such as the Large Hadron Collider (LHC).

In particular, I have worked 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 also studied the collider implications of such particles at the LHC.

In addition I worked on models with extended scalar sectors where the electroweak scalar doublet is augmented with additional scalar multiplets. In one scenario where a nutrinophillic scalar doublet is added to generate neutrino mass, we studied the resulting charged scalar phenomenology at the LHC and showed that one required the very high luminosity run of the LHC to search for such a particle. The SM gauge symmetry remains unchanged but new SM singlet neutrino states are added which are odd under a discrete Z_2 symmetry along with the new $SU(2)_L$ scalar doublet. Tiny neutrino masses are generated when the discrete Z_2 symmetry is spontaneously broken with a very tiny vacuum expectation value for the new doublet. This makes the charged Higgs chromophobic. In another study we considered the otherwise excluded sequential fourth-generation fermion model by including an $SU(2)_L$ triplet scalar in the model (HTM4). We showed that with such a setup, the sequential 4th-generation fermions can survive existing experimental constraints from the Higgs data at LHC as well as electroweak precision data constraints.

In supersymmetric extensions of the SM, the minimal extension is now strongly constrained by LHC data. I studied other well motivated scenarios like the left-right supersymmetry (LRSUSY) and next to minimal su-

persymmetric SM (NMSSM) looking at collider signals as well as cosmological implications. In the LRSUSY model we analyzed a new collider signal resulting from the pair production and decay of a light doubly-charged Higgsino to an even lighter doubly-charged Higgs boson. We focus on the minimal left-right supersymmetric model with automatic R-parity conservation, which predicts such a light doubly-charged Higgs boson and its Higgsino partner at the TeV scale, which are singlets of $SU(2)_L$. We investigated the distinctive signatures of these particles with four leptons and missing transverse energy in the final state at the Large Hadron Collider and show that the discovery reach for both particles can be increased in this channel. As the inclusion of right-chiral sneutrino superfields is a rather straightforward addition to a supersymmetric scenario we found that a neutral scalar with a substantial right sneutrino component is often a favoured dark matter candidate in such cases. In this context, we focused on the tentative signal in the form of a monochromatic photon, which may arise from dark matter annihilation. We studied the prospect of such a right sneutrino dark matter candidate in the contexts of both MSSM and NMSSM extended with right sneutrino superfields, with special reference to the Fermi-LAT data.

Publications:

1. U. Maitra, B. Mukhopadhyaya, S. Nandi, Santosh Kumar Rai and A. Shivaji, *Searching for an elusive charged Higgs at the Large Hadron Collider,* Phys. Rev. D **89**, 055024, (2014). [arXiv:1401.1775 [hep-ph]].

2. S. Banerjee, M. Frank and Santosh Kumar Rai, *Higgs data confronts Sequential Fourth Generation Fermions in the Higgs Triplet Model,* Phys. Rev. D **89**, 075005, (2014). [arXiv:1312.4249 [hep-ph]].

3. K. S. Babu, A. Patra and Santosh Kumar Rai, *New Signals for Doubly-Charged Scalars and Fermions at the Large Hadron Collider,* Phys. Rev. D **88**, 055006, (2013).

4. S. Chakdar, K. Ghosh, S. Nandi and Santosh Kumar Rai, *Collider signatures of mirror fermions in the framework of a left-right mirror model,* Phys. Rev. D **88**, 095005, (2013).

Preprints:

1. A. Chatterjee, D. Das, B. Mukhopadhyaya and Santosh Kumar Rai, *Right Sneutrino Dark Matter and a Monochromatic Photon Line,* arXiv:1401.2527.

2. D. Karabacak, S. Nandi and Santosh Kumar Rai, *New signals for singlet Higgs and vector-like quarks at the LHC,* (in preparation).

Conference/Workshops Attended:

1. *Sangam @ HRI : Instructional Workshop in Particle Physics*, India, March 2014.

Invited Lectures/Seminars:

1. *Higgs Beyond the Standard Model*, Sangam @ HRI : Instructional Workshop in Particle Physics, Harish-Chandra Research Institute, Allahabad, India, March 2014.

Other Activities:

1. Taught course at HRI integrated PhD program titled *Numerical Methods*.

2. Mentored theory projects of Mr. Kasinath Das and Mr. Siddharth Dwivedi.

3. Member, Organising Committee of *Sangam @ HRI : Instructional Workshop in Particle Physics*, March 2014.

4. Member, VSP Committee and Library Committee.

Sumathi Rao

Research Summary:

During the period, April 2013-March 2014, I have been mainly working on topological phases of matter.

We have introduced superconducting proximity effects in Weyl semi-metals by tunnel coupling one of its surfaces to an s-wave superconductor using the Green's function approach. We have found that the band structure develops coherence peaks as the coupling to the superconductor is increased in both inversion symmetry broken and time-reversal symmetry broken Weyl semi-metals. The surface states get gapped by the proximity effect, but for the Weyl semi-metal, the nodes remain unaffected, and in that sense, no true gap develops. Consequently, we have also found that at finite chemical potentials, there is greater penetration of the the pairing amplitude into the Weyl semi-metal than the topological insulator and hence a greater possibility of experimental detection at the other naked surface.

We have been studying silicene, which is a layered material like graphene, but with a buckled sub-lattice structure. So unlike in graphene, which has low energy excitations, which are massless Dirac fermions, the low energy excitations of silicene are massive. However, its mass can be tuned by an electric field, and silicene phases include both massive (insulator and topological insulator phases) and massless (metal) phases. We are studying the proximity effect on silicene - in particular, we are studying superconductor-ferromagnet junction in silicene.

With an aim to study non-abelian anyons, we have been looking at generalisations of the Haldane model, including the Pachos model. Our aim is to include interactions in such models to give rise to fractional quantum Hall like states and non-abelian excitations.

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

Publications:

1. Udit Khanna, Saurabh Pradhan and Sumathi Rao, *Transport and STM studies of hyperbolic surface states of topological insulators*, Phys. Rev. **B87**, 245411, (2013)

Preprints:

1. Udit Khanna, Arijit Kundu, Saurabh Pradhan and Sumathi Rao, *Proximity induced superconductivity in Weyl semi-metals*, (in preparation)

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

Conference/Workshops Attended:

1. *Workshop on Interferometry in meso and nano-systems*, ICTP, Italy, April 8-12, 2013

2. *Frontiers in condensed matter physics*, Delhi University, India, April 12-14, 2013

3. *Workshop on topological insulators*, HRI, India, July 9-12, 2013

4. *Topology and non-equilibrium in low dimensional electronic systems (TOPSYS13)*, Max Planck Institute for Complex systems, Dresden, Germany, Sept 16-20, 2013

5. *India-U.K. Conference on ' From graphene to topological insulators' (GATI 2014)*, Kolkata, India, Jan 27-29, 2014

6. *International conference on research and curriculum development for gifted minds*, New Delhi, India, Feb 6, 2014

7. *Topological states in quantum matter*, IIT Kharagpur, India, Feb 8, 2014

8. *Quantum information processing and applications (QIPA)*, HRI, India, Feb 14-20, 2014

Visits to other Institutes:

1. Dept. of Physics, Macquarie University, Sydney, Australia, April 28 - May 31, 2013

2. Dept of Physics, University of Basel, Basel, Switzerland, Sept 23-27, 2013

Invited Lectures/Seminars:

1. *Charge and spin fractionalisation in helical edge states*, Workshop on Interferometry in meso and nano-systems, ICTP, Italy, April 12, 2013

2. *Topological insulators and their surface states*, Workshop on Frontiers in condensed matter physics, Delhi University, April 14, 2013

3. *Topological insulators*, Dept of Physics, Macquarie University, Sydney, Australia, May 2, 2013

4. *Exotic excitations in topological insulators*, Workshop on Topological insulators, HRI, Allahabad, July 10, 2013

5. Poster on *Transport and STM studies of surface states of topological insulators* , Workshop on Topology and non-equilibrium in low dimensional electronic systems (TOPSYS13), Dresden, Sept 2014

6. *Surface states in two and three dimensional topological insulators*, Dept. of Physics, University of Basel, Basel, Switzerland, Sept 25, 2013

7. *From topological insulators to Weyl semi-metals*, India-UK conference on From graphene to topological insulators (GATI 2014), Jan 27-29, 2014

8. *Attracting girls to science*, International conference on research and curriculum development for gifted minds, New Delhi, Feb 6, 2014

9. *Introduction to Weyl semi-metals*, Conference on Topological states in quantum matter, IIT Kharagpur, Feb 8, 2014

10. *Majorana modes and non-abelian statistics*, Conference on Quantum information processing and applications, HRI, Feb 14-20, 2014

Other Activities:

1. Organised a Workshop on Topological Insulators from July 9-12, 2013 (with G. V. Pai)

2. Member, Academic council, MNNIT, Allahabad

3. Convenor, Faculty Advisory Committee and Daycare Committee, HRI

4. Member, Local works committee, Housing allotment committee, HRI

5. Taught quantum field theory I - (Aug 2013 - Dec 2013 and Jan 2014 - May 2014)

Ashoke Sen

Research Summary:

My work during April 2013 - March 2014 has been on several aspects of string theory.

1. I proposed a general procedure for computing physical quantites in string theory and quantum field theories at finite coupling with the help of S-duality and appropriate interpolation formula between strong and weak coupling. This was later applied to $N = 4$ supersymmetric Yang-Mills theory in collaboration with Christopher Beem, Leonardo Rastelli and Balt van Rees and to compactified string theory with Roji Pius.

2. Together with Boris Pioline and Jan Manschot I analyzed the mutation symmetries of our conjectured Coulomb branch formula for computing the Hodge numbers of quiver moduli spaces. We also proposed a generalized mutation symmetry of the Coulomb branch formula that reduces to the standard mutation under appropriate restrictions. We tested this conjecture in many examples.

3. Together with Roji Pius and Arnab Rudra I developed a general procedure for computing finite mass renormalization for massive states in string theory.

Publications:

1. A. Sen, "S-duality Improved Superstring Perturbation Theory," JHEP **1311** (2013) 029 [arXiv:1304.0458 [hep-th]].

2. J. Manschot, B. Pioline and A. Sen, "Generalized quiver mutations and single-centered indices," JHEP **1401** (2014) 050 [arXiv:1309.7053 [hep-th]].

Preprints:

1. C. Beem, L. Rastelli, A. Sen and B. C. van Rees, "Resummation and S-duality in N=4 SYM," arXiv:1306.3228 [hep-th].
2. R. Pius and A. Sen, "S-duality Improved Perturbation Theory in Compactified Type I / Heterotic String Theory," arXiv:1310.4593 [hep-th].
3. R. Pius, A. Rudra and A. Sen, "Mass Renormalization in String Theory: Special States," arXiv:1311.1257 [hep-th].
4. R. Pius, A. Rudra and A. Sen, "Mass Renormalization in String Theory: General States," arXiv:1401.7014 [hep-th].
5. A. Sen, "Microscopic and Macroscopic Entropy of Extremal Black Holes in String Theory," arXiv:1402.0109 [hep-th].

Invited talks at Conferences / Workshops / Schools

1. Strings 2013, Seoul, South Korea, June 2013
2. GR20, Warsaw, Poland, July 2013
3. Rikkyo Math-Phys conference, Tokyo, January 2014
4. Asian Winter School, Puri, January 2014

Visits to other Institutes:

1. KIAS, Seoul, Korea, June 2013

Academic recognition/Awards:

- D.Sc (Hon): IIT Kanpur, 2013
- D.Sc. (Hon): IIT, Bombay, 2013
- D.Litt (Hon): Jadavpur University, 2013
- M.P. Birla prize, MP Birla Foundation, 2013

Prasenjit Sen

Research Summary:

My research was focussed on first principles electronic structure calculations of materials using density functional theory. The materials I studied include atomic clusters, both in the gas phase and deposited on substrates, two dimensional electronic materials, and bulk oxide materials. In atomic clusters, stability of 3d transition metal doped aluminum clusters were studied. $FeAl_4$ and $CoAl_3$ were identified as stable clusters. There stability was found to originate from aromaticity rather than electronic shell effects. Diffusion of Fe adatoms and clusters on a hybrid hexagonal BN-C sheet were studied using ab initio molecular dynamics approach. It was found that individual Fe atoms diffuse very quickly to form clusters which then diffuse as a whole and ultimately get stuck at the C-B interface. Properties of silver clusters containing up to eight atoms deposited on a graphite surface were studied. They were found to retain their gas phase structures and electronic properties because of weak interaction with the substrate, in agreement with experimental findings. The proposed spin gapless semiconductor material Co-doped $PbPdO_2$ was studied and the energetics and magnetic effects of Co doping were explored.

Publications:

1. A. Singh, C. Majumder and P. Sen, *Do Ag_n (up to $n = 8$) clusters retain their identity on graphite? Insights from first-principles calculations including dispersion interactions,* J Chem. Phys. **140**, 164705, (2014)

2. V. Chauhan, A. Singh, C. Majumder and P. Sen, *Structural, electronic and magnetic properties of binary transition metal aluminum clusters: Absence of electronic shell structure,* J Phys. Cond. Mat. **26**, 015006, (2013)

3. P. Srivastava, B. J. Nagare, D. G. Kanhere and P. Sen, *Electronic structure of the spin gapless material Co-doped $PbPdO_2$,* J Appl. Phys. **114**, 103709, (2013)

4. 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,* J Phys. Chem. C **117**, 21763, (2013)

Preprints:

1. V. M. Medel, A. C. Reber, V. Chauhan, P. Sen, A. Köster and P. Calaminici and S. N. Khanna, *Nature of Valence Transition and Spin Moment in Ag_nV^+ Clusters,* (submitted).

Visits to other Institutes:

1. Abdus Salam International Centre for Theoretical Physics, Trieste, Italy, April-May 2013,
2. SISSA, Trieste, Italy, May 2014.
3. CNR, Pisa, Italy, May 2014.

Invited Lectures/Seminars:

1. *Transition metal dopants in other metal clusters: From shell models to magnetic superatoms and beyond*, Condensed Matter Physics Seminar, ICTP, Trieste, May 2013.

Other Activities:

1. Reviewing papers for *Phys, Chem. Chem. Phys.*, *Zeitschrift für Naturforschung A.*, *Sol. State Comm.*.
2. Member of the Editorial Board of the journal *Physica Scripta*.

Ujjwal Sen

Research Summary:

During the past year, the foci of my research interests have been the study of multiparty quantum states from fundamental as well as applied perspectives and the interface of quantum many-body physics with quantum information.

Quantifying multiparty quantum correlations is an area that is receiving unprecendented attention from researchers worldwide. It is long suspected that multiparty quantum correlations are responsible for a wide variety of cooperative quantum phenomena and are necessary for several enabling quantum technologies. Research in this direction is crippled by

the nonavailability of physically meaningful and mathematically tractable measures of multiparty quantum correlations. We have recently tried to break ground by providing two directions in which the problem can be addressed and solved to a certain degree. We have proposed a measure of genuine multiparty entanglement, which we refer to as the generalized geometric measure, that is computable for any pure state of an arbitrary number of parties in any dimension. Moreover, we have also proposed the use of monogamy concepts in identifying multiparty quantum correlation measures, that are tractable even for mixed states.

We have used the generalized geometric measure, that was introduced by us in 2010, for characterizing properties of many-body quantum systems. We have introduced a new method, and which we have termed as the "Density Matrix Recursion Method", to analytically calculate single-, two-, and multisite properties of quantum Heisenberg ladders. We have also used the same measure to characterize frustrated quantum spin models. On a more fundamental side, we have used the measure to obtain a new connection between the time-energy uncertainty relation in quantum mechanics and quantum correlations.

We have proposed a new mean field theory, which we have termed as the "virtual-site correlation mean field theory", for dealing with interacting many-body Hamiltonians, which are not amenable to analytical methods and for which numerical techniques are also difficult to apply.

Monogamy of quantum correlations form one of the connecting strings in the plethora of quantum correlation measures that have been proposed in the literature. Along with using the monogamy concept for defining multiparty quantum correlation measures, we have also found evidence that all quantum correlation measures are monogamous for almost all multiparty quantum states. We have also shown that there exists a monogamy constraint in the form of an "exclusion principle" for the capacity of sending classical information via quantum channels: For any multiparty state, pure or mixed, of an arbitrary of parties in arbitrary dimensions, at most one receiver for a given sender can have a quantum advantage in dense coding, if the multiparty state is used as a quantum channel for the quantum dense coding protocol.

We have identified a new characteristic of shared quantum systems that, although quantum, is different from any quantum correlation. This has the potential of becoming a new resource in shared quantum systems.

We have proposed a new quantum state of a large number of subsystems that has the potential of being a stable Schrödinger cat.

Publications:

1. U. Mishra, A. Sen(De), and U. 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. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Exclusion principle for quantum dense coding,* Phys. Rev. A **87**, 052319 (2013)

3. 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,* Phys. Rev. A **87**, 052318 (2013).

4. K.R.K. Rao, H. Katiyar, T.S. Mahesh, A. Sen(De), U. Sen, and Anil Kumar, *Multipartite quantum correlations reveal frustration in a quantum Ising spin system,* Phys. Rev. A **88**, 022312 (2013)

5. H.S. Dhar, A. Sen(De), and U. Sen, *Characterizing Genuine Multisite Entanglement in Isotropic Spin Lattices,* Phys. Rev. Lett. **111**, 070501 (2013)

6. R. Prabhu, A. Sen(De), and U. Sen, *Genuine multiparty quantum entanglement suppresses multiport classical information transmission,* Phys. Rev. A **88**, 042329 (2013)

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

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

9. R. Prabhu, A. Sen(De), and U. Sen, *Nonergodic classical correlations lead to ergodic quantum correlations in low-dimensional spin models,* Europhys. Lett. **102** 30001 (2013)

10. A. Sen(De) and U. Sen, *Virtual-site correlation mean field approach to criticality in spin systems,* Phys. Lett. A **377**, 1832 (2013)

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

Preprints:

1. M.N. Bera, R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Limit on Time-Energy Uncertainty with Multipartite Entanglement,* arXiv:1303.0706
2. Asutosh Kumar, R. Prabhu, A. Sen(De), and U. Sen, *Do Large Number of Parties Enforce Monogamy in All Quantum Correlations?,* arXiv:1312.6640
3. U. Mishra, A. Sen(De), and U. Sen, *Local Decoherence-free Macroscopic Quantum states,* arXiv:1401.3208

Conference/Workshops Attended:

1. *"Colloquium on recent trends in theoretical physics", organized by the Srinivasa Ramanujan Institute of Basic Sciences (SCRIBS), Government of Kerala*, India, August 2013.
2. *"13th Asian Quantum Information Science Conference" at IMSc, Chennai*, India, August 2013.
3. *"Meeting on Quantum Simulations" at IISc, Bengaluru*, India, September 2013.
4. *"International Meet on Quantum Correlations and Logic, Language and Set Theory" at IIT Jodhpur*, India, December 2013.
5. *"International Program on Quantum Information (IPQI)" at IOP, Bhubaneswar*, India, February 2014.

Invited Lectures/Seminars:

1. *Resonating Valence Bond States: a quantum information perspective*, ICFO Seminar, ICFO-The Institute of Photonic Sciences, Barcelona, Spain, June 2013.
2. *Quantum Information Perspective of Many-Body Systems*, Meeting on Transport in Topological Insulators, Harish-Chandra Research Institute, Allahabad, India, July 2013
3. *What is Entanglement?*, Colloquium on recent trends in theoretical physics, Srinivasa Ramanujan Institute of Basic Sciences (SCRIBS), Thiruvananthapuram, India, August 2013.

4. *Scaling of Entanglement in Resonating Valence Bond States*, Meeting on Quantum Simulations, Indian Institute of Science, Bengaluru, India, September 2013.

5. *Beyond Quantum Correlations*, Seminar, Indian Institute of Technology Madras, Chennai, India, October 2013.

6. *Resonating Valence Bond States: a quantum information perspective*, International Meet on Quantum Correlations and Logic, Language and Set Theory, Indian Institute of Technology Jodhpur, India, December 2013.

7. *Monogamy of Shared Quantum Quantities*, Seminar, Indian Institute of Technology Kanpur, India, January 2014.

8. Interaction session with students, Indian Institute of Technology - Benaras Hindu University, Varanasi, India, February 2014.

9. *Strong subadditivity of von Neumann entropy in quantum information*, in International Program on Quantum Information (IPQI), Institute of Physics, Bhubaneswar, India, February 2014. [pdf available on program website.]

Visits to other Institutes:

1. Department of Applied Mathematics, University of Calcutta, Kolkata, India, April 2013.

2. ICFO-The Institute of Photonic Sciences, Barcelona, Spain, June 2013.

3. Universitat Autonoma de Barcelona, Spain, June 2013.

4. University of Gdansk, Poland, June 2013.

5. National Quantum Information Centre in Gdansk, Poland, June 2013.

6. Srinivasa Ramanujan Institute of Basic Sciences, Thiruvananthapuram, India, August 2013.

7. Institute of Mathematical Sciences, Chennai, India, August 2013.

8. Indian Institute of Sciences, Bengaluru, India, September 2013.

9. Indian Institute of Technology Madras, Chennai, India, October 2013.

10. Indian Institute of Technology Jodhpur, India, December 2013.
11. Indian Institute of Technology Kanpur, India, January 2014.
12. Department of Physics, Indian Institute of Technology - Benaras Hindu University, Varanasi, India, February 2014.
13. Institute of Physics, Bhubaneswar, February 2014.

Other Activities:

1. Taught a one-semester course on "Numerical methods" during Jan-May 2013.
2. Taught a one-semester course on "Advanced Quantum Mechanics" during Jan-May 2014.
3. Guiding the theses of Utkarsh Mishra, Asutosh Kumar, and Sudipto Singha Roy of HRI.
4. Guided projects of the following HRI graduate students.
   (a) Sudipto Singha Roy, on "Quantum Information Processing Techniques to handle Traingular Spin Lattices" (Summer 2013).
   (b) Sudipto Singha Roy, on "Density Matrix Renormalization Group" (Aug-Dec 2013).
   (c) Sarif Khan, on "Monogamy of Concurrence" (Jan-May 2014).
5. Organized a collaborative meeting on "Quantum Information Processing and Applications (QIPA-2013)" held at HRI in December 2013, with 61 speakers and 64 other participants. The other organizers were Prabhu R., Arun K. Pati, and Aditi Sen(De) of HRI, and was also locally organized all members of the QIC group at HRI. www.hri.res.in/~qipa13/
6. Guiding the project work of a student, Rupashree Karmakar, of Calcutta University, under the visiting students programme (VSP) of HRI (June 2014).
7. Serving as the convenor of the Computer Committee, and member of the Cluster Computing Committee at HRI.
8. Serving as coordinator of the DAE project to the QIC group within the XII plan.

9. Serving as referees in national and international journals.

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

R. Prabhu

Research Summary:

During the academic year 2013-2014, I have carried out my research work on different aspects of quantum information and its interface with the many-body physics. In particular, I investigated the behavior of quantum correlation and its usefulness in different quantum information processing tasks in multiparticle systems by collaborating with students, postdocs and faculties of the Quantum Information and Computation group at HRI.

Following are the succinct description of the work done during this academic year:

- We proved that almost all pure quantum states of systems consisting of a large number of subsystems are monogamous with respect to all quantum correlation measures of both the entanglement-separability and the information-theoretic paradigms, indicating that the volume of the monogamous pure quantum states increases with an increasing number of parties.

- Studied the ergodic-nonergodic properties of quantum correlations in various low-dimensional many-body systems, like XY and Heisenberg spin models.

- We showed that the classical capacity of a quantum state, as quantified by its ability to perform dense coding, respects an exclusion principle, for arbitrary pure or mixed three-party states in any dimension. In other words, the exclusion principle implies that, if Alice has a quantum advantage in transferring classical information to Bob, she must necessarily have no quantum advantage in transferring the same to Charu.

- We established a complementarity relation between the capacity of classical information transmission by employing a multiparty quantum state as a multiport quantum channel and the corresponding genuine multipartite entanglement.

Publications:

1. R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Genuine Multiparty Quantum Entanglement Suppresses Multiport Classical Information Transmission,* Phys. Rev. A **88**, 042329, (2013)

2. R. Prabhu, Arun Kumar Pati, Aditi Sen(De), and Ujjwal Sen, *Exclusion Principle for Quantum Dense Coding,* Phys. Rev. A **87**, 052319, (2013)

3. 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**, 052319, (2013)

4. R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Nonergodic classical correlations lead to ergodic quantum correlations in low-dimensional spin models,* Europhys. Letts. **102**, 30001, (2013)

Preprints:

1. Asutosh Kumar, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Do Large Number of Parties Enforce Monogamy in All Quantum Correlations?* arXiv:1312.6640 [quant-ph]

Conference/Workshops Attended:

1. *International Program on Quantum Information*, India, February 17-28, 2014.

2. *Meeting on Quantum Information Processing and Applications*, India, December 2-8, 2013.

Visits to other Institutes:

1. IISER Pune, Pune, India, July 2013.

2. IIT-BHU, Varanasi, India, February 2014.

Invited Lectures/Seminars:

1. *Quantum technologies*, INSPIRE Internship Science Camp, RKG Engineering College, Ghaziabad, Uttar Pradesh, 15th May, 2013.

2. *Restrictions on sending classical information using quantum states*, IISER Pune, Pune, Maharashtra, 30th July, 2013.

3. *Classical Communication in a Quantum World*, IIT-BHU, Varanasi, Uttar Pradesh, 18th February, 2014.

Academic recognition/Awards:

- Life membership, Indian Physics Association, Mumbai, since August 2013.

Other Activities:

1. Mentor of Mr. Tomoghna Das for the project on Quantum Information in Continuous Variable Systems at HRI, January - May, 2014.

2. Mentor of Mr. Gautam Sharma and Mr. Chiranjib Mukhopadhyay for their Numerical Projects undertaken as partial fulfillment of the Numerical Methods course at Harish-Chandra Research Institute, Allahabad, August - December 2013.

3. Mentor of Mr. K. M. Sreenath (from IISERTVM, Thiruvananthapuram) under Visiting Students Programme at Harish-Chandra Research Institute, Allahabad, May - July, 2013.

4. Taught Atomic Physics part of Atomic, Molecular and Cold Atoms course, Harish-Chandra Research Institute, Allahabad, January - May, 2013.

5. Co-organizer of the Meeting on Quantum Information Processing and Applications, Harish-Chandra Research Institute, Allahabad, December 02-08, 2013.

6. Referee of international journals like Physical Review Letters and Physical Review A

7. Member of Cluster Committee at Harish-Chandra Research Institute, Allahabad.

Taushif Ahmed

Research Summary:

New physics may show up as tiny deviations from the prediction of the Standard Model(SM)! To exploit this possibility it is absolutely necessary to make the theoretical predictions at very high accuracy within the SM and beyond. Multiloop computations play a crucial role to achieve this golden task. The complexity of these computations grows very rapidly with the increase of number of loops and/or external particles. We have done a 2-loop computation within the framework of massless QCD. The process involves three massless gluons and one massive spin-2 particle. We assume that the SM fields couple to spin-2 object through SM energy-momentum tensor. Due to presence of huge number of 2-loop Feynman diagrams, namely 2362, and involvement of spin-2 field, the computation becomes highly challenging! Using integration-by-part (IBP) and Lorentz (LI) identities, the number of independent 2-loop integrals to be computed is reduced substantially from 2362 to 21! After substituting the results of these integrals and performing required renormalization, we have got the final renormalized result. We find that our results exhibit the right infrared structure confirming the factorization property of QCD amplitude even with tensorial insertion.

Precise theoretical predictions for Drell-Yan(DY) production of pair of leptons and Higgs boson production in gluon fusion at next to next to leading order (NNLO) in perturbative Quantum Chromodynamics (pQCD) have played an important role to test the Standard Model to an unprecedented accuracy. The recent computation on the full threshold contributions to Higgs production at N^3LO in QCD contains valuable information on the soft gluons resulting from virtual and real emission partonic subprocesses. Using those along with factorization of soft and collinear divergences, renormalization group invariance and resummation of threshold contributions, we obtain the corresponding soft gluon contributions to DY production and determine the missing delta part of the N^3LO at threshold. This has a substantial contribution to the full N^3LO inclusive cross-section.

Preprints:

1. Taushif Ahmed, Maguni Mahakhud, Prakash Mathews, Narayan Rana and V. Ravindran, *Two-Loop QCD Correction to massive spin-2 resonance $\to$ 3 gluons* [in preparation]

2. Taushif Ahmed, Maguni Mahakhud, Narayan Rana and V. Ravindran, *Drell-Yan production at threshold in N^3LO QCD* [in preparation]

Conference/Workshops Attended:

1. *CTEQ School on QCD and Electroweak Phenomenology*, University of Pittsburgh, Pennsylvania, USA, July 2013.

2. *Discussion Meeting on Radiative Corrections*, Institute of Physics, Bhubaneswar, India, March 2014.

Visits to other Institutes:

1. The Institute of Mathematical Sciences, Chennai, India, September 2013.

Shrobona Bagchi

Research Summary:

Understanding the nature of correlations is one of the greatest challenge in the area of quantum information science. Given a multipartite state one usually tries to characterize the amount of total correlation comprising of both the classical correlation and the quantum correlation contained in the composite system. Quantum mutual information and the entanglement of purification are two such measures of total correlation in a quantum state. We study various important properties of the quantum mutual information and the entanglement of purification. We show that the quantum mutual information is monogamous for pure tripartite states, and find the conditions for monogamy for mixed states. We also explore the monogamy, additivity properties and as well as a new lower bound for the entanglement of purification. In this regard we use the method of semidefinite relaxations for polynomial optimization for obtaining a viable lower bound numerically.

Apart from the quantum correlations, the uncertainty principle is a cornerstone of quantum mechanics. We derive a new uncertainty relation for two arbitrary unitary operators acting on physical states of any Hilbert space (finite or infinite dimensional). We show that the uncertainty in the unitary operator is directly related to the visibility of quantum interference in an interferometer where one arm of the interferometer is affected

by a unitary operator. This shows that quantum states cannot be prepared which will display maximum visibility in the interference for two non-commuting unitary operators. The amount of visibility for two general unitary operators is non-trivially lower bounded.

Preprints:

1. Shrobona Bagchi, Arun K Pati *Monogamy properties of entanglement of purification* (in preparation)
2. Shrobona Bagchi, Arun K Pati *Uncertainty relation for arbitrary unitary operators* (in preparation)

Other Activities:

1. Tutorship for Mathematical Methods I (Course Instructor- Prof Dileep Jatkar): August 2013-December 2013.

Aditya Banerjee

Research Summary:

As my first work, I, with Prof. G. Venkat Pai, studied a variant of the one-dimensional topological Kitaev chain that is capable of supporting multiple Majorana zero modes at its endpoints and using a transfer matrix based approach, we determined the modifications in its topological phase diagrams when the chemical potential is made to spatially vary following periodic, Gaussian and box disordered profiles. Our basic model was a Kitaev chain with next-nearest neighbour hopping and superconducting pairing which had been shown earlier to support two orthogonal Majorana zero modes at its endpoints in certain regimes of its parameter space. The transfer matrix approach is essentially a re-expression of the conditions/constraints that normalizability of wavefunctions impose on the parameters. Demanding that a Majorana zero mode exists, and hence demanding that its wavefunction be real, normalizable and localized at the system's endpoints, gives us some mathematical conditions on how the parameters of the system should be in order to support the said Majorana zero modes. These parameter conditions thus yield a phase diagram differentiating a topological phase from the trivial phase. This approach can be seen to be a rather simple analytical method to determine Majorana

phase diagrams, an alternative to exact diagonalization or explicit winding number computations in appropriate cases, and can be particularly effortless when the system's chemical potential follows a site-dependent profile. In the course of this work, some limitations of this method were also realised. A preprint documenting this work is in preparation and nearly complete.

Independently, I am presently working on analytically figuring out the effects and interplay of weak interactions and disorder on a time-reversal invariant topological superconductor in one dimension that was recently shown (by other authors) to support a Kramers pair of Majorana zero modes at its endpoints that are topologically protected by the time-reversal symmetry. Using the analytical methods of abelian bosonization, replica method and perturbative renormalization group, I intend to find out to what extent the phase diagram is affected by the simultaneous presence of weak Gaussian disorder and weak interaction in such a system and consequently how they affect the fate of the Kramers-Majorana pair. A related study, based on the supersymmetry method to study the sole effects of disorder analytically, is also intended to eventually be included in this work. This work was begun towards the end of the 2013-14 academic session and is in steady progress at the moment.

In addition, I also attempted studying the effects of some other manifestations of interactions, particularly the Coulomb drag effect and quadratic corrections to the dispersion, on the topological Majorana models in one dimension. However, it turned out these do not lead to anything new or interesting. The effect of Coulomb drag on the topological phase diagrams, if present, was found to be essentially the same as what has been already known about the general effects of interaction on the one-dimensional topological superconductors. In addition, it became clear that, as expected, quadratic corrections to dispersion of the base quantum wire do not have any noteworthy consequences on the fate of the Majorana modes.

Preprints:

1. Aditya Banerjee and G. Venkat Pai, *A transfer matrix based study of one-dimensional class BDI topological superconductors with spatially varying chemical potential profiles,* (in preparation)

Conference/Workshops Attended:

1. *US-India Advanced Studies Institute School on Thermalization : From Glasses to Black Holes*, ICTS Bangalore, India, June 2013

2. *Transport in Topological Insulators*, HRI Allahabad, India, July 2013.

3. *Joint ICTP-VAST-APCTP Regional School on Theoretical Physics in Topological Phases and Quantum Computation*, VAST Hanoi, Vietnam, December 2013.

4. *School and Workshop on Physics of Cold Atoms*, HRI Allahabad, India, February 2014.

Other Activities:

1. I tutored for the Quantum Field Theory-I course for the two semesters (August-December and January-May) in the academic year 2013-14.

Shankha Banerjee

Research Summary:

During this year I have worked on various Beyond the Standard Model (BSM) scenarios.

We have worked on the effects of Higher-dimensional (dimension 6) operators in the Higgs-Gauge boson sector. We have shown that on changing the Lorentz structure of the Higgs couplings to the Gauge bosons, on the introduction of the aforementioned operators, the kinematics of the final state particles change. We see differences in various kinematic distributions. Thus, we see that the non-trivial changes in the couplings of the Higgs with the gauge bosons alter the cut-efficiencies (cuts applied by the experiments to separate the signal from the backgrounds) considerably from the Standard Model (SM) expectations. This study was done in the light of the recent Large Hadron Collider (LHC) Higgs data. Using these, we obtained bounds on some of the dimension 6 operators.

In another work, we tried to salvage the 4^{th} generation chiral fermions by introducing an extended Higgs sector, in the form of a Higgs triplet. The huge enhancement in the gluon fusion production cross-section of the

Higgs due to the 4^{th} generation quarks, is countered by the mixing between the Higgs doublet and triplet. Here, we considered the latest LHC Higgs data to show the allowed parameter space for such 4^{th} generation sequential fermions. We further showed that only a part of the above parameter space survives when one considers the contribution of the new physics to the Peskin-Takeuchi parameters.

Publications:

1. Shankha Banerjee, P.S. Bhupal Dev, Subhadeep Mondal, Biswarup Mukhopadhyaya and Sourov Roy, *Invisible Higgs Decay in a Supersymmetric Inverse Seesaw Model with Light Sneutrino Dark Matter,* JHEP **1310**, 221 (2013)

2. Shankha Banerjee, Satyanarayan Mukhopadhyay and Biswarup Mukhopadhyaya, *Higher dimensional operators and LHC Higgs data : the role of modified kinematics,* Phys. Rev. D **89**, 053010 (2014)

3. Shankha Banerjee, Mariana Frank and Santosh Kumar Rai, *Higgs data confronts Sequential Fourth Generation Fermions in the Higgs Triplet Model,* Phys. Rev. D **89**, 075005 (2014)

Conference/Workshops Attended:

1. *Sangam @ HRI*, Allahabad, India, March 2014.

2. *Discussion meeting on Electroweak Symmetry Breaking (EWSB) and Status of Flavour Physics*, Guwahati, India, February 2014.

3. *Workshop on High Energy Physics and Phenomenology (WHEPP)*, Puri, India, December 2013.

Visits to other Institutes:

1. Indian Association for the Cultivation of Science, Kolkata, India, April 2013

Invited Lectures/Seminars:

1. *Higher dimensional Operators and LHC Higgs data : the role of modified kinematics*, Workshop on High Energy Physics and Phenomenology (WHEPP), Puri, Odisha, India, December 2013.

Other Activities:

1. Teaching assistant for Particle Physics course, August-December, 2013.

Sourav Bhattacharya

Research Summary:

I have worked with Prof. Tapas K Das and his students on the acoustic analogue model of general relativity. We have looked into the problem of analogue gravity from an astrophysical point of view. Prescisely, we have perturbed the accretion rate of an ideal irrotational fluid, in static and stationary axisymmetric spacetimes and have derived the acoustic metric. This metric is identical to that of one gets via the well known perturbation of velocity potential. I have also worked on uniqueness of stationary axisymmetric black hole solutions with spin-1/2 and conformal scalar fields. I studied the renormalizability of self interacting scalar field theory in genral Riemann-Cartan spacetime at two loop level, and the effect of a positive cosmological constant on the propagation of vacuum polarized photons.

Publications:

1. Sourav Bhattacharya and Hideki Maeda, *Can a black hole with conformal scalar hair rotate?,* Physical Review D **89**, 087501, (2014)

2. Sourav Bhattacharya and Amitabha Lahiri, *Mass function and particle creation in Schwarzschild-de Sitter spacetime,* The European Physical Journal C **73**, 2673, (2013)

3. Sourav Bhattacharya, *Note on black hole no hair theorems for massive forms and spin-1/2 fields,* Physical Review D **88**, 044053, (2013)

Preprints:

1. Deepika B Ananda, Sourav Bhattacharya, Tapas K Das, *Acoustic geometry through perturbation of accretion rate : I - radial flow in static spacetime,* arXiv:1406.4262 [astro-ph.HE]

2. Deepika B Ananda, Sourav Bhattacharya, Tapas K Das, *On the realizability of relativistic acoustic geometry under a generalized perturbation scheme for axi-symmetric matter flow onto black holes,* arXiv:1406.3697 [astro-ph.HE]

3. Deepika B Ananda, Sourav Bhattacharya, Tapas K Das, *Acoustic geometry through perturbation of accretion rate : II - axisymmetric flow in static spacetime,* in preparation

4. Sourav Bhattacharya, *Renormalization of self interacting scalar field theory in general Riemann-Cartan spacetime,* in preparation

Visits to other Institutes:

1. Department of Physics, Rikkyo University, Tokyo, Japan, August, 2013.

2. Deparment of Physics, Charles University in Prague, Prague, Czech Republic, December, 2013.

3. Centre for theoretical studies, IIT-Kharagpur, Kharagpur, India, February, 2014.

Other Activities:

1. Working as a referee for journals "Classical and Quantum Gravity" and "The European Physical Journal C".

Nabarun Chakrabarty

Research Summary:

During the academic session April 2013-March 2014, I have mainly investigated the issue of additional Higgs particles, typical to a Beyond Standard Model (BSM) scenario.

In one project, We have looked into the prospects of producing a heavier Higgs in a future muon collider. It is found that the process of radiative return of a photon in $\mu^+\mu^-$ collisions can produce a generic heavy Higgs with a higher cross section as compared to a heavy Higgs production in an e^+e^- collider. We have identified the region of the parameter space where this happens in a model independent parametrization of the scenario. Also, it is also seen that the heavy Higgs so produced via radiative return can decay to a $t\bar{t}$ pair and that will decay to lighter quarks. This particular decay mode bears the signature of a heavy Higgs and is observable in a collider search. This project is in the completion stages.

In another project, we have investigated the theoretical constraints of perturbativity, unitarity and vacuum stability in the context of a Two Higgs Doublet Model (2HDM). As emphasized in a number of recent works, the electroweak vacuum in the Standard Model (SM) is stable upto the energy scales of $10^8 - 10^{11}$ GeV. This variation in the energy scale is accounted by the variation of the top quark mass. Recquiring the SM vacuum to be stable all the way upto the Planck scale would imply a heavier Higgs and a lighter top, a possibility which is strained by the recent experimental data. However, in a generic scenario with an extended scalar sector, such as the 2HDM, the electroweak vacuum can be made stable upto the Planck scale. We have considered the Renormalization Group evolution of the 2HDM couplings and identified the parameter space compatible with vacuum stability, unitarity and perturbativity upto various scales. We found even the variation of the top mass does not go into conflict with a stable vacuum upto high scales, though, modifies the allowed parameter spaces to some extent. In addition, we have carved out further subregions in the so obtained parameter spaces which are allowed by the recent LHC data on the Higgs signal strengths for various channels. This work too, has been completed and expects to be arxived soon.

Conference/Workshops Attended:

1. CTEQ Summer School on QCD and Electroweak Theory, July 2013, University of Pittsburgh, Pittsburgh, USA.

2. Sangam@HRI, March 2014, HRI, Allahabad, India.

Other Activities:

1. Teaching assistant for the Quantum Field Theory-II course, HRI, Fall 2013. Instructor: Prof. Anshuman Maharana

Vikas Chauhan

Research Summary:

During the last year, I have studied structural, electronic and magnetic properties of a single $3d$ transition metal (TM) aluminum clusters using first-principles approach based on density functional theory. Our motivation to study these clusters was to identify the suitable candidates for '**Magnetic Superatom'**.
While we have not been able to identify any possible candidates for magnetic superatoms in these series, we have found some very interesting properties in them. We have found that $FeAl_4$, and $CoAl_3$ clusters have enhanced stability as indicated by their second order energy difference, hardness and adiabatic spin excitation energy. However, they have no net magnetic moment. Most importantly we found that spherical shell models cannot describe the electronic structure of TM doped aluminum clusters, in contrast to binary TM doped alkali and alkaline earth clusters. In fact we have shown that stability of $FeAl_4$, and $CoAl_3$ can be associated with their aromatic behaviour as revealed by their negative NICS (Nucleus independent chemical shift) values.
In recent work, we have investigated the evolution in the atomic structure, bonding characteristics, stability, and the spin magnetic moment of neutral and cationic VAg_n clusters. This work is motivated by the experimental study of the VAg_n^+ clusters in which VAg_5^+ and VAg_7^+ were found to be stable. We found that VAg_5^+ and VAg_7^+ have enhanced stability in agreement with the experiments, indicated by their large HOMO-LUMO gap and Δ_n^2. In addition we show that the stability of VAg_5^+ and VAg_7^+ can be explained in terms of exchange splitting within the 1D shell orbitals of these clusters.

Publications:

1. V. Chauhan, A. Singh, C. Majumder, P. Sen, *Structural, electronic and magnetic properties of binary transition metal aluminum clusters : absence of electronic shell structure*, J. Phys. Cond. Matt. **26**, 015006, (2014)

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

Conference/Workshops Attended:

1. *International symposium on Clusters, Cluster Assemblies and Nano-scale Materials*, India, March, 2014.

Abhishek Chowdhury

Research Summary:

In collaboration with Arunabha Saha of HRI, we revisit the study of the phase structure of higher spin black holes carried out in arXiv: 1210.0284 using the "canonical formalism". In particular we study the low as well as high temperature regimes. We show that the Hawking-Page transition takes place in the low temperature regime. The thermodynamically favored phase changes from conical surplus to black holes and then again to conical surplus as we increase temperature. We then show that in the high temperature regime the diagonal embedding gives the appropriate description. We also give a map between the parameters of the theory near the IR and UV fixed points. This makes the "good" solutions near one end map to the "bad" solutions near the other end and vice versa.

Preprints:

1. Abhishek Chowdhury and Arunabha Saha, *Phase Structure of Higher Spin Black Holes,* arXiv:1312.7017 [hep-th]

Conference/Workshops Attended:

1. *National String Meet 2013*, India, December 2013.
2. *8th Asian Winter School on Strings, Particles and Cosmology*, India, January 2014.
3. *ICTP Spring String School*, Italy, March 2014.

Other Activities:

1. Tutored Gravitation Course by Prof. Anirban Basu, Fall, 2013 .

Ujjal Kumar Dey

Research Summary:

During this academic year I have worked on minimal Universal Extra Dimensional models (mUED). In mUED we consider one extra spatial dimension on top of conventional four dimensional Minkowski space-time. Unlike other extra dimensional models, in mUED all the Standard Model (SM) fields can propagate in the extra dimension. The effect of the extra dimension is reflected by the presence of infinite Kaluza-Klein towers of SM particles. The lowest lying states of this tower (zeroeth mode) are identified with the observed SM particles. The higher modes are higher in masses and thus require high energy experiments to probe them. In an ongoing project we are trying to see the effects of second KK level top quark and how they can be probed in LHC. (Ujjal Kumar Dey and Amitava Raychaudhuri)

After the discovery of Higgs particle, the only fundamental scalar particle observed till now in LHC, its natural to explore the scenario with more Higgs like particles. The simple extension of scalar sector of SM may lead to very interesting phenomenology as well as cure some shortcomings of SM itself. One such model is two Higgs doublet model (2HDM). In an ongoing work we are studying the high scale validity of this model taking various constraints and LHC observations into account. (Nabarun Chakrabarty, Ujjal Kumar Dey and Biswarup Mukhopadhyaya)

In a different work on extended scalar sector we investigated the scalar potential of a general S_3-symmetric three Higgs doublet model. From the unitarity and stability conditions of the potential we showed that there may be many new scalars present below 1 TeV. Also we showed how some observations in LHC can prove or falsify the model. (Dipankar Das and Ujjal Kumar Dey)

Publications:

1. Ujjal Kumar Dey and Tirthasankar Ray, *Constraining minimal and non-minimal UED models with Higgs couplings,* Phys. Rev. D **88**, 056016, (2013)

2. Anindya Datta, Ujjal Kumar Dey, Amitava Raychaudhuri and Avirup Shaw, *Boundary Localized Terms in Universal Extra-Dimensional Models through a Dark Matter perspective,* Phys. Rev. D **88**, 016011, (2013)

3. Anindya Datta, Ujjal Kumar Dey, Amitava Raychaudhuri and Avirup Shaw, *Universal extra dimensions : life with BLKTs,* J. Phys.: Conf. Ser. **481**, 012006, (2014)

4. Dipankar Das and Ujjal Kumar Dey, *Analysis of an extended scalar sector with S_3 symmetry,* Phys. Rev. D **89**, 095025, (2014)

Preprints:

1. Nabarun Chakrabarty, Ujjal Kumar Dey and Biswarup Mukhopadhyaya, *High-scale validity and other constraints on a two-Higgs doublet scenario: a study including LHC data,* (in preparation)

2. Ujjal Kumar Dey and Amitava Raychaudhuri, *Signal of $n = 2$ excitations of Extra-Dimensional Models at the LHC and future facilities,* (in preparation)

Conference/Workshops Attended:

1. *Summer School on Particle Physics and Workshop on Higgs and Beyond Standard Model Physics*, ICTP, Italy, June, 2013

2. *WHEPP XIII*, Puri, India, December, 2013.

3. *EWSB & Flavours in the light of LHC*, IIT Guwahati, India, February, 2014.

Invited Lectures/Seminars:

1. *Constraining non-minimal UED from dark matter analysis*, Workshop on Higgs and Beyond Standard Model Physics, ICTP, Trieste, Italy, June, 2013.

Aritra Gupta

Research Summary:

The IceCube (IC) has recently reported three ultra-high energy cascade events, with two events being seen at almost the same energy of = 1.1 PeV, and a third one seen at = 2.1 PeV. In addition, they also see events (both cascade and muon-track) at lower energies ranging from 10 - 400 TeV.We are trying to explore whether the high energy events can come from some dark matter particles and hence we can get the first direct hints of dark matter in IceCube.

Preprints:

1. Atri Bhattacharya, Raj Gandhi, Aritra Gupta ,*Multi-component Dark Sector, Extra-galactic neutrinos and PeV events at the IceCube* ,(in preparation).

Conference/Workshops Attended:

1. *INVISIBLES SCHOOL 2013*, UNITED KINGDOM, JULY, 2013.
2. *SANGAM WORKSHOP*, INDIA, MARCH, 2014.

Abhishek Joshi

Research Summary:

Under the guidance of Prof. Pinaki Majumdar, I am currently studying disorder driven superfluid to insulator transition in fermi systems.The model used is negative U hubbard model in the presence of speckle disorder,using ED-MC based scheme. I am also interested in studying finite temperature properties of bosons in mott as well as superfluid phases in the bose hubbard model.

Conference/Workshops Attended:

1. *Ultra-Cold Atom School at HRI Allahabad*, India,Feb 2013

Other Activities:

1. I was the tutor for the course Condensed Matter Physics-I in the semester August-December 2013.

Udit Khanna

Research Summary:

In the previous year, I worked on proximity effect between an s-wave superconductor and a weyl semi-metal, to find the changes in the band-structure of the semi-metal and properties of the pairing amplitude induced. For this, I studied a simplified model of weyl semi-metals coupled at one surface to a BCS superconductor, through exact diagonalization and a Green's function approach. Superconductivity is found to be induced in the surface states of the semi-metal and the pairing amplitude is a mixture of spin singlet s-wave and spin triplet p-wave components. This work was done with Arijit Kundu, Saurabh Pradhan and Sumathi Rao.

Preprints:

1. Udit Khanna, Arijit Kundu, Saurabh Pradhan and Sumathi Rao, *Proximity induced superconductivity in Weyl semi-metals,* (in preparation).

Conference/Workshops Attended:

1. *US-India Advanced Studies Institute on Thermalization*, India, June 2013.
2. *ICTP-VAST-APCTP School on Topological Phases and Quantum Computation*, Vietnam, December 2013.
3. *School and Workshop on Physics of Cold Atoms*, India, February 2014.

Other Activities:

1. Tutorship for the course Condensed Matter Physics 2, August-December, 2013.

Asutosh Kumar

Research Summary:

Correlation is a reciprocal relation between two or more entities. Quantum correlations, entanglement in particular, are key resources for performing exotic tasks in quantum information theory. Therefore, characterization and quantification of quantum correlations is an important area of research. It has been observed that quantum correlations, unlike classical ones, cannot be distributed at will among the members of a multipartite quantum system. This restriction on arbitrary sharing of quantum correlations has been dubbed as "monogamy of quantum correlations" in the literature. Quantum correlations may satisfy monogamy for some states and violate it for others. That is, not all quantum correlations are monogamous for all quantum states. Monogamy of quantum correlations has been found useful in a variety of applications, including in quantum cryptography and conceptualization of multiparty quantum correlations. Thus identifying conditions under which quantum correlations will be monogamous for given quantum states is extremely important. It has been proven that a non-monogamous quantum correlation can always be made monogamous by increasing its exponent. We find evidence for another avenue towards achieving monogamy: almost all multipartite pure states are monogamous with respect to all quantum correlation measures, indicating that the volume of the monogamous pure quantum states increases with an increasing number of parties. Nonetheless, we identify important classes of pure states that remain non-monogamous with respect to quantum discord and quantum work-deficit, irrespective of the number of qubits. We provide conditions for which a given quantum correlation measure satisfies vis-à-vis violates monogamy. In another project we study the decoherence effects on three-qubit pure states, under different local quantum channels, using monogamy as the quantum correlation measure.

Generating entanglement is a non-trivial task. We provide algorithms for generating entangled states from computational states. We introduce two multiple-qubit controlled-unitary gates with different working principles. We employ these gates and existing quantum gates to propose simple and efficient algorithms that generate multi-term orthonormal entangled Bell-like bases. We observe that all algorithms known thus far for constructing entangled bases turn out to be special cases of our method. The quantum correlations of these bases are investigated; we find that the Bell-like bases

obtained by using different controlled-unitaries have different entanglement contents. We also learn that the "monogamy score" is able to distinguish these bases in situations where other quantum correlations fail to do so, indicating that monogamy score is a fine-grained quantum correlation measure. Our approach can be extended to qudit systems as well.

Preprints:

1. Asutosh Kumar, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Do Large Number of Parties Enforce Monogamy in All Quantum Correlations?*, arXiv:1312.6640 [quant-ph] (HRI-P-14-04-002).

2. Asutosh Kumar, *Simple Algorithms for Multi-term Bell-like Bases and Their Quantum Correlations,* arXiv:1404.6206 [quant-ph] (HRI-P-14-04-003).

3. Asutosh Kumar, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Discriminating Quantum Channels through Monogamy of Quantum Correlations,* (in preparation).

Conference/Workshops Attended:

1. *Meeting on Quantum Information Processing and Applications (QIPA-13)*, India, December 2013.

2. *International Program on Quantum Information (IPQI-14)*, India, February 2014. Presented a poster entitled "Almost All Multipartite Pure States are Monogamous".

Invited Lectures/Seminars:

1. *Special Relativity*, Scientific Hindi Workshop, Harish-Chandra Research Institute, Allahabad, May 2014.

2. *From Bits to Qubits and Quantum Computation*, Scientific Hindi Workshop, Harish-Chandra Research Institute, Allahabad, May 2014.

Other Activities:

1. Member of local organizing committee of *Quantum Information Processing and Applications (QIPA-13)*, Harish-Chandra Research Institute, December 2013.

2. Tutored Advanced Quantum Mechanics (QM-2) course, Harish-Chandra Research Institute, Jan-May 2014.

Maguni Mahakhud

Research Summary:

Extra dimension models are interesting scenarios to tackle the hierarchy problem. Depending on the geometry of the extra dimension(s), the two popular options are: (a) flat extra dimension model (ADD) and (b) the warped extra dimension model (RS) with a large curvature. In both these models, only the graviton is allowed to permeate the bulk which leads to different spectrum of spin-2 Kaluza-Klein (KK) modes in 4-dimensions. The spin-2, KK modes couple to the Standard Model (SM) particles through the energy momentum tensor of the SM.
These beyond SM model scenarios could alter the SM predictions by additional virtual KK mode exchanges and real KK mode productions. Dedicated groups in both ATLAS and CMS collaborations are engaged in the analysis for extra dimension searches in various processes like di-lepton, di-photon, mono-jet, mono-photon productions etc. To put stringent bounds on the parameters of these BSM models, control on the theoretical uncertainties is essential. Renormalisation and factorisation scale dependences of a cross section to a particular order in perturbation theory give an estimate of the uncalculated higher order corrections. Presently next-to-leading order (NLO) QCD calculations have been done for di-lepton , di-photon and di-electroweak gauge boson productions via virtual KK modes in addition to the SM contributions. These virtual contributions have been incorporated in the AMC@NLO frame work and results to NLO+PS accuracy are now available for most of the di-final state processes . In all these processes the factorisation scale dependence reduces substantially and in addition the NLO correction is in fact significant. For the above processes, the leading order (LO) is of the order $\mathcal{O}(\alpha_s^0)$, the renormalisation scale dependence starts only at NLO in QCD. To control the renormalisation scale dependence one would have to go to next-to-next-to-leading order (NNLO) order.

A full NNLO QCD contribution requires the knowledge of graviton-quark-antiquark $G^* \to q\overline{q}$ and graviton-gluon-gluon $G^* \to gg$ form factors up to two-loop level in QCD in addition to double real emission and one-loop single real emission scatter processes at the parton level. Here G^* denotes the virtual graviton.

In our 1st paper we take the first step towards the full NNLO computation by evaluating these form factors to two-loop level in QCD and in the 2nd paper we used this result to calculate NNLO threshold corrections to Drell Yan Productions in TeV Scale Gravity models.There we have discussed phenomenological results in ADD and RS model in NNLO threshold limit.In our 3rd paper we are calculating the amplitude for $G^* \rightarrow ggg$. The work is in progress. Also in another project using recent full N^3LO threshold corrections for Higgs production,we are calculating the full N^3LO threshold corrections for Drell Yan processes in SM.This work is also in progress.

Publications:

1. Daniel de Florian, Maguni Mahakhud , Prakash Mathews, Javier Mazzitelli, V. Ravindran, *Quark and gluon $spin-2$ form factors to two-loops in QCD,* JHEP **1402**,035, (2014)

2. Daniel de Florian, Maguni Mahakhud , Prakash Mathews, Javier Mazzitelli, V. Ravindran, *Next-to-Next-to-Leading Order QCD Corrections in Models of TeV-Scale Gravity,* JHEP **1404**,028, (2014)

Preprints:

1. Taushif Ahmed, Maguni Mahakhud, Prakash Mathews, Narayan Rana and V. Ravindran, *Two-Loop QCD Correction to massive spin-2 resonance $\rightarrow$ 3 gluons* [In Preparation]

2. Taushif Ahmed, Maguni Mahakhud, Narayan Rana and V. Ravindran, *Drell-Yan production at threshold in N^3LO QCD* [In Preparation]

Conference/Workshops Attended:

1. *Discussion Meeting on Radiative Corrections*, Institute of Physics, Bhubaneswar, 5-10th March 2014

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, March 2013

2. Institute of Mathematical Sciences, Chennai, September 2013

Invited Lectures/Seminars:

1. *QCD Corrections*, Institute of Mathematical Sciences, Chennai,23rd July 2013.

Ushoshi Maitra

Research Summary:

In the usual 5-dimensional Randall-Sundrum scenario with warped geometry of the extra compact dimension, the Goldberger-Wise mechanism for stabilisation of the radius of compactification can lead to a scalar field called the radion. The radion can have implications in TeV-scale physics, which can be especially noticeable if its vacuum expectation value (vev) is not far above a TeV. However a large mass of the first graviton excitation, which seems to be suggested by recent search limit, tends to make the radion vev, far too large in the minimal model. We showed that this is not the case if a Gauss-Bonnet term, containing higher powers of the curvature, is present in the 5-dimensional action. As a result, a radion with vev in the range 1-1.5 TeV can be consistent with the first graviton excitation mass well above 3 TeV.

We explored the constraints on the parameter space of 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, using the most recent data from higgs searches at the Large Hadron Collider (LHC) and the Tevatron. We calculated contributions from both the scalar mass eigenstates arising from radion-higgs kinetic mixing in all important search channels. The most important channel to be affected is the decay via WW^*, where no invariant mass peak can discern the two distinct physical states. Improving upon the previous studies, we performed a full analysis in the WW^* channel, taking into account the effect of various cuts and interference when the two scalar are closely spaced. We examine both cases where the experimentally discovered scalar is either 'higgs-like' or 'radion-like'. The implications of a relatively massive scalar decaying into a pair of 125 GeV scalars is also included. Based on a global analysis of the current data, including not only a single 125 GeV scalar but also another one with mass over the range 110 to 600 GeV, we obtain the up-to-date exclusion contours in the parameter space. Side by side, regions agreeing with the data within 68% and 95% confidence level based on a χ^2 -minimization procedure, are also presented.

We studied the signals for a "fermiophobic" charged Higgs boson present in an extension of the standard model with an additional Higgs doublet and right handed neutrinos, responsible for generating Dirac-type neutrino masses. We studied the pair production of the charged Higgs at the Large Hadron Collider (LHC), which can be relatively light and still allowed by experimental data. The charged Higgs decays dominantly into a W boson and a very light neutral scalar present in the model, which decays invisibly and passes undetected. We found that the signal for such a charged Higgs is overwhelmed by the standard model background and will prove elusive at the 8 TeV run of the LHC. We presented a cut-flow based analysis to pinpoint a search strategy at the 14 TeV run of the LHC which can achieve a signal significance of 5 σ for a given mass range of the charged Higgs.

Publications:

1. Nishita Desai, Ushoshi Maitra and Biswarup Mukhopadhyaya, *An updated analysis of radion-higgs mixing in the light of LHC data,* JHEP **10**, 93, (2013)

2. Ushoshi Maitra, Biswarup Mukhopadhyaya, S. Nandi, Santosh Kumar Rai and Ambresh Shivaji, *Searching for an elusive charged Higgs at the Large Hadron Collider,* Phys. Rev. D **89**, 055024, (2014)

Preprints:

1. Ushoshi Maitra, Biswarup Mukhopadhyaya and Soumitra SenGupta, *Reconciling small radion vacuum expectation values with massive gravitons in an Einstein-Gauss-Bonnet warped geometry scenario,* 1307.3018 [hep-ph]

Conference/Workshops Attended:

1. *WHEPP 13*, India, December, 2013,

2. *SANGAM@HRI*, India, March 2014.

Visits to other Institutes:

1. Indian Association for Cultivation of Science, Kolkata, India, April 2013,

2. Indian Association for Cultivation of Science, Kolkata, India, June 2013.

Invited Lectures/Seminars:

1. *Constraints on radion-Higgs Mixing from the recent LHC data*, Constraints on radion-Higgs Mixing from the recent LHC data, TIFR, Puri, December 2013.

Manoj Kumar Mandal

Research Summary:

Presently I am studying the effect of parton shower (PS) for several important physics processes in the Standard Model(SM) and beyond the SM (BSM) at next to leading order (NLO) in Quantum Chromodynamics (QCD) to be able to have the realistic predictions at the Large Hadron Collider(LHC). With the wealth of data produced by the LHC already, it is very important to have these physical processes at the NLO+PS accuracy for the testing of various theoretical predictions against the experimental data.
I with my guide and other collaborators have completed the matching of the parton shower at NLO for the production of di-bosons and di-leptons in the ADD model at the LHC, hereby setting the stage to test the theoretical prediction of the ADD model. We have studied the role of parton shower on various observables and a selection of results has been presented for the 14 TeV LHC.
We have introduced a framework, based on an effective field theory approach, that allows one to perform characterisation studies of the boson recently discovered at the LHC, for all the relevant channels and in a consistent, systematic and accurate way. The production and decay of such a boson with various spin and parity assignments can be simulated by means of multi-parton, tree-level matrix elements and of next- to-leading order QCD calculations, both matched with parton showers. Several sample applications are presented which show, in particular, that beyond-leading-order effects in QCD have non-trivial phenomenological implications.
We have completed the calculation of tri-photon production at hadron colliders at NLO and subsequently interfaced the results to Parton Shower (PS) Monte Carlo codes using the MC@NLO formalism and showed the effects of the PS on the observables and the results have been presented in NLO+PS accuracy.

Publications:

1. 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, *A framework for Higgs characterisation*, JHEP **1311**, 043, (2013)

2. R. Frederix, M. 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*, Eur.Phys.J. C **74**, 2745, (2014)

Preprints:

1. M. K. Mandal, Prakash Mathews, V. Ravindran, Satyajit Seth, *Three photon production in SM at NLO+PS accuracy at the LHC*, arXiv:1403.2917

Conference/Workshops Attended:

1. *Discussion Meeting on Radiative Corrections*, INDIA, March, 2014.

2. *Sangam @ HRI*, INDIA, March, 2014.

Visits to other Institutes:

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

Invited Lectures/Seminars:

1. *Introduction to NLO I: virtual corrections*, Discussion Meeting on Radiative Corrections, Institute of Physics, Bhubaneswar, March, 2014.

2. *Introduction to NLO II : Real Corrections*, Discussion Meeting on Radiative Corrections, Institute of Physics, Bhubaneswar, March, 2014.

Mehedi Masud

Research Summary:

During the 2013-14 academic year, I have been working on two topics. The first one is on the Long Baseline Neutrino Experiment (LBNE). This involves a comprehensive study of LBNE to answer outstanding questions

in the neutrino sector. The sensitivities to the mass hierarchy, the octant of θ_{23} and to CP violation were analysed, using data from beam and atmospheric neutrinos. We have also shown the effect of T2K and NOνA to these sensitivities. We evaluated the dependencies on the precision with which θ_{13} is measured by reactor experiments, on the detector size, beam power and exposure time, on detector magnetization, and on the systematic uncertainties achievable with and without a near detector. I have co-authored two papers on these topics and have shown that a 35 kt LBNE with a near detector will resolve the eight-fold degeneracy that is intrinsic to long baseline experiments and will meet the primary goals of oscillation physics that it is designed for.

The second work (in progress) also involves LBNE. In a long baseline experiment, the values of the parameters of neutrino oscillation are extracted at the far detector and it requires the knowledge of neutrino beam flux, which in turn is obtained at the near detector. The final aim of my work is to analyse the impact of nuclear effects and final state interactions (FSI) on the measurement of these oscillation parameters in LBNE due to misreconstruction of non-quasi-elastic events as quasi-elastic events at low energies. Currently, I am studying the FSI in different neutrino-nucleus reactions. I am using two event generators GENIE and GiBUU for various simulations needed for this study.

Publications:

1. Vernon Barger, Atri Bhattacharya, Animesh Chatterjee, Raj Gandhi, Danny Marfatia, Mehedi Masud. *Configuring the Long-Baseline Neutrino Experiment.* Phys. Rev. D **89**, 011302 (2014)

Preprints:

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

Conference/Workshops Attended:

1. *Sangam @HRI*, India, March, 2014

Utkarsh Mishra

Research Summary:

During the academic year 2013-14, I have worked on the dynamics of bipartite and multipartite quantum correlations in many-body quantum systems. In particular, I have investigated the effect of local decoherence on a class of macroscopic quantum superposition states and the behavior of classical and quantum correlations in the ground state of disordered Heisenberg models on the one-dimensional spin-$1/2$ lattice.

Entangled state of a large number of qubits is assumed to be the basic requirement for quantum computation. Such "macroscopic quantum superposition states" put forward two main conceptual problems: (1) how to define their macroscopicity and (2) how does the quantum coherence (entanglement or other quantum correlation measures) in these states behave under the effect of local and global decoherence. It is known that under the effect of local decoherence, the entanglement of all hitherto proposed macroscopic quantum superposition states decays with increasing system size. An important task is thus to find macroscopic quantum states which are robust against the local decoherence. We have proposed a class of macroscopic quantum states composing two macroscopically distinct states: one of them is formed by the N- qubit Dicke state while and the other is a product state of all the qubits. The two states of the macroscopic sector are distinguished in terms of their amount of violation of local realism. We have shown that the resultant macroscopic state is more resistant to particle loss and local depolarization as compared to other well known macroscopic superposition states, including the Greenberger-Horne-Zeilinger state. To quantify the quantum coherence properties of the state under the effect of local environment, we have used the logarithmic negativity and quantum discord between the microscopic and macroscopic parts of the resultant state. We further extended our study by considering other local noisy channels like local phase damping and local amplitude damping. We have also examined the logarithmic negativity and quantum discord for the same class of states, but for differing numbers of excitations in the Dicke state, and have compared their entanglement decay with other macroscopic quantum states.

Quantum statistical mechanics studies the macroscopic properties of systems composed of many quantum particles. The statistical models without any disorder have been understood up to some extent but the corresponding disordered models are less investigated. We have studied the dynamics of magnetization and two-site classical correlations as well as bipartite

and multipartite quantum correlations in disordered quantum spin -$1/2$ models on the one-dimensional lattice in the presence of external magnetic fields. For bipartite quantum correlation, we have used the concurrence, while the generalized geometric measure (GGM) is used to quantify multiparty quantum correlation. Since the model is not exactly solvable even in the ordered case, we have performed the calculation using both exact diagonalization and the DMRG method. We find that the disordered system gives an enhanced value for both classical and quantum correlations in some parameter range of the Hamiltonian. This phenomenon is known as "order from disorder in the literature". Moreover, we find a region where the effect of individual disorder in the nearest neighbor couplings does not correspond to the effect of combined disorders in the couplings simultaneously for the GGM.

Preprints:

1. Utkarsh Mishra, Aditi Sen(De), and Ujjwal Sen, *Local Decoherence-free Macroscopic Quantum states,* arXiv:1401.3208.

2. Ameya Deepak Rane, Utkarsh Mishra, Anindya Biswas, Aditi Sen(De), and Ujjwal Sen, *Benford's Law gives better scale exponents in phase transitions of quantum XY models,* arXiv:1405.2744.

3. Utkarsh Mishra, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Constructive interference between disordered couplings in quantum spin models,* (in preparation).

Conference/Workshops Attended:

1. *Asian Quantum Information Science Conference (AQIS)*, India, August 2013, presented a poster entitled "Schrödinger cat resistant to particle loss and local decoherence ".

2. *Meeting on Quantum Simulations (QS)*, India, September 2013, presented a poster entitled "Ergodicity-breaking of quantum correlations in low-dimensional spin system".

3. *Meeting on Quantum Information Processing and Applications (QIPA)*, India, December 2013, presented a poster entitled "Constructive interference between quenched couplings enhances multiparty quantum correlations in Heisenberg spin models".

4. *International Program on Quantum Information (IPQI)*, India, February 2014, presented a poster entitled "Quantum Noise: Challenges for Cat".

Invited Lectures/Seminars:

1. *Kinetic Theory of gases*, Scientific Hindi Workshop, Harish-Chandra Research Institute, Allahabad, May 2014.

Other Activities:

1. Contributed to Talent Search Examination, Physics, organized by HRI for secondary and higher secondary level students , November, 2014.

2. Member of local organizing committee of *Meeting on quantum Information Processing and Applications (QIPA-13), HRI, December 2013*.

Avijit Misra

Research Summary:

In the academic year 2013-2014, I have worked on characterization and quantification of multiparty quantum correlations and its applications in many body system. I have also worked on the thermodynamical significance of multiparty quantum correlations in relevant quantum system.

Quantum discord is a measure of quantum correlations beyond the entanglement -separability paradigm. It is conceptualized by using the von Neumann entropy as a measure of disorder. We define a class of quantum correlation measures as differences between total and classical correlations, in a shared quantum state, in terms of the relative Rényi and Tsallis entropies. While we mostly use the sandwiched relative entropies, we also compare our results with those obtained by using the traditional relative entropies. We find that the measures fulfill intuitively satisfactory axioms for quantum correlations. We evaluate, analytically and numerically, the measures for paradigmatic classes of shared states. We use the measures to detect the quantum critical point in the transverse quantum Ising model, where we find that the measures can be used to remove an

unquieting feature of quantum discord. Furthermore, the measures provide better exponents in finite-size scaling than the ones for other known detectors of the same quantum phase transition.

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 minimize the loss of quantum correlation.

Preprints:

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

2. Avijit Misra, Anindya Biswas, Arun K. Pati, Aditi Sen(De), and Ujjwal Sen, *Quantum Correlation with Sandwiched Relative Entropies,* (in preparation)

Conference/Workshops Attended:

1. *Meeting on Quantum Information Processing and Applications (QIPA)*, India, December, 2013.

2. *International Program on Quantum Information (IPQI)*, India, February, 2014.

Visits to other Institutes:

1. Bose institute, Kolkata, India, February, 2014.

Other Activities:

1. Teaching Assistant for the Statistical Mechanics course during January - May, 2014.

2. Member of local organizing committee of *meeting on Quantum Information Processing and Applications (QIPA)*, HRI, India, December, 2013.

Debasis Mondal

Research Summary:

During the period April 2013-March 2014, I worked on the "Quantum Speed Limit For Mixed States Using Experimentally Realizable Metric" with my guide Prof. Arun Kumar Pati(HRI). The minimal time required for a system to evolve between two different states is an important notion for developing ultra-speed quantum computer and communication channel. Here, we introduced a new metric for non-degenerate density operator evolving along unitary orbit and showed that this is experimentally realizable operation dependent metric on quantum state space. Using this metric, we obtained the geometric uncertainty relation that leads to a new quantum speed limit. Furthermore, we showed that this gives a tighter bound for the evolution time compared to any other bound. We also obtained a Levitin kind of bound for mixed states. We proposed how to measure this new distance and speed limit in quantum interferometry. Finally, we studied the lower bound for the evolution time of a quantum system for any completely positive trace preserving map using this metric.

I also focused to apply this newly defined experimentally realizable metric in other aspects of quantum information theory.

Preprints:

1. Debasis Mondal and Arun Kumar Pati, *Quantum Speed Limit For Mixed States Using Experimentally Realizable Metric,* arXiv:1403.5182 [quant-ph]

Conference/Workshops Attended:

1. *Quantum Information Processing and Applications (QIPA-2013)*, India, December 2013.
2. *Workshop on Black Hole Information Paradox*, India, February, 2014.
3. *International programme on Quantum Information*, India, February 2014.

Visits to other Institutes:

1. Institute Of Physics, Bhubaneswar, India, February 2014.
2. Raman Research Institute, Bangalore, India, April 2014.

Swapnamay Mondal

Research Summary:

A. Exact results for the BPS index are known for a class of BPS dyons in type II string theory compactified on a six dimensional torus. We set up the problem of counting the same BPS states in a duality frame in which the states carry only Ramond-Ramond charges. We explicitly count the number of states carrying the lowest possible charges and investigate whether the result agrees with the result obtained in other duality frames. This work has been going on under the guidance of Prof. Ashoke Sen and in collaboration with Abhishek Chowdhury and Richard Garavuso, and has recently been succesfully completed.

B. We wish to realize an explicit field theory description of $(G_k \times G_1)/G_{k+1}$ WZW model . We expect this field theory to be 2 dimensional BF theory, with may be some possible modifications. We wish to explore this possibility by calculating correlations functions and other observables and mathcing them with known results. This work has been going on under the supervision of Prof. Rajesh Gopakumar and in collaboration with Abhishek Chowdhury, Arunabha Saha, Sachin Jain and Tomohisa Takimi.

C. Recently an systematic procedure for mass renormalization of certain special states was proposed in the paper arXiv:1311.1257 by Sen et al. We wish to explicitly calculate two loop mass renormalization for special states in SO(32) heterotic string theory. This work is going on under the guidance of Prof. Ashoke Sen and in collaboration with Abhishek Chowdhury , Arnab Rudra and Roji Pius .

Conference/Workshops Attended:

1. *National Strings Meet*, India, December 2013.
2. *8th Asian Winter School on Strings, Particles and Cosmology*, India, January 2014.

Other Activities:

1. tutor of Particle Physics course, January-May, 2014.

Saurabh Niyogi

Research Summary:

I study the physics of Kaluza-Klein (KK) top quarks in the framework of a non-minimal Universal Extra Dimension (nmUED) with an orbifolded (S^1/Z_2) flat extra spatial dimension in the presence of brane-localized terms (BLTs). Such terms change the mass spectrum, but most importantly, they affect the coupling constants also. A few benchmark scenarios are chosen for preliminary studies of the decay patterns of the KK top quarks and their production rates at the LHC. The entire new model has been implemented in publicly available package FeynRules which generates suitable code for running in event generator MadGraph.

In another publication, I study the effects of top-Higgs anomalous coupling in the production of a pair of Higgs boson via gluon fusion at the LHC. The introduction of anomalous ttH coupling can alter the hadronic double Higgs boson cross section and can lead to characteristic changes in certain kinematic distributions. I perform a global analysis based on available LHC data on the Higgs to constrain the parameters of ttH anomalous coupling. Possible overlap of the predictions due to anomalous ttH coupling with those due to anomalous trilinear Higgs coupling is also studied.

Publications:

1. Asesh Krishna Datta, Kenji Nishiwaki, Saurabh Niyogi, *Non-minimal Universal Extra Dimensions with Brane Local Terms: The Top Quark Sector,* Journal of High Energy Physics (JHEP) **1401**, 104, (2014)

2. Kenji Nishiwaki, Saurabh Niyogi, Ambresh Shivaji, *ttH Anomalous Coupling in Double Higgs Production,* Journal of High Energy Physics (JHEP) **1404**, 011, (2014)

Visits to other Institutes:

1. University of Helsinki and Helsinki Institute of Physics, Helsinki, Finland, September-December 2013,

Ashis kumar Pal

Research Summary:

Studying Non-Dissipative Shocks In Schwarzschild Black Hole

Accretion is a process, by which a massive object(like compact object,star) captures its surrounding fluid(Fluid is assumed to be ideal).If the fluid has some non zero angular momentum disc structure formed around the object.In literature there are various models for this disc height(e.g, where the disc height is constant is called constant height model and where it is proportional to the radial distance is called conical model). This accretion flows into a black hole with constant specific energy and angular momentum which allows transonic solutions (where the speed of fluid passes to the speed of the sound, the point where these two speeds become equal is called critical point). There exists values of specific energy and angular momentum for which part of parameter space P(E,λ,γ) allows multiple critical points. With the theory of Dynamical Systems the physical critical points can be separated out to construct the phase portrait that connects infinity to the black hole horizon. We have shown that(in the two model described above) there exists p1(E,λ,γ) ϵ P(E,λ,γ) that allows discontinuous change of flow variables between infinity and the horizon of the black hole causing the formation of shock.

Other Activities:

1. Tutor in the Astrophysics course

Roji Pius

Research Summary:

In the past one year I have been trying to understand off-shell string theory. Usual formulation of string theory compute S-matrix elements directly only for external states which do not suffer from mass renormalization. Because usual conformal or superconformal framework of superstring perturbation theory allows us to use only those external vertex operators carrying momenta satisfying the tree level on-shell condition and this in turn makes string amplitude of external states receiving mass renormalisation ill defined. Also conventional formalism does not tell how us

to do a systematic perturbative expansion of string theory around a dynamically shifted vacuum which does not satisfy classical equation. Such situation do occur in string theory. For example in many compactifications of SO(32) heterotic string theory on Calabi-Yau 3-folds, one loop correction shifts the vacuum. To address these problems in a direct way we need a string theory analog of off-shell Green's functions. This is possible if we generalise Polyakov prescription for computing string amplitudes for off-shell vertex operators. But such off-shell string amplitudes depends on spurious data defined on the world sheet of string. Nonetheless with Ashoke Sen and Arnab Rudra we showed that physical quantities defined using off-shell amplitudes like S-matrix elements and physical masses are independent of any such spurious data. Also using this off-shell formalism we gave a prescription for perturbatively computing physical quantities around dynamically shifted vacuum. I am planning to continue exploring this off-shell formulation of string theory with the aim of an improved understanding of string perturbation theory.

Preprints:

1. R. Pius, A. Rudra, A. Sen, *String Perturbation Theory Around Dynamically Shifted Vacuum,* arXiv:1404.6254 [hep-th]

2. R. Pius, A. Rudra, A. Sen, *Mass Renormalization in String Theory: General States,* [arXiv:1401.7014 [hep-th]

3. R. Pius, A. Rudra, A. Sen, *Mass Renormalization in String Theory: Special States,* [arXiv:1311.1257 [hep-th]

4. R. Pius, A. Sen, *S-duality Improved Perturbation Theory in Compactified Type I / Heterotic String Theory,* [arXiv:1310.4593 [hep-th]

Conference/Workshops Attended:

1. *Workshop on Black Hole Information Paradox*, India, February 2014.

2. *Asian Winter School on Strings, Particles and Cosmology*, India, January 2014.

3. *National String Meeting*, India, December 2013.

Visits to other Institutes:

1. ICTS, Bengaluru, India, March 2014.
2. IIT Kharagpur, Kharaghpur, India, March 2014.

Invited Lectures/Seminars:

1. *Off-shell string perturbation theory*, Informal lectures, ICTS, Bengaluru, March 2014.
2. *Mass renormalization in string theory*, National String Meeting, IIT Kharagpur, Kharagpur, December 2014.

Other Activities:

1. Tutor: classical mechanics, first year course, August-December, 2013.

Saurabh Pradhan

Research Summary:

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

I have also studied the effect of superconductivity on the weyl semi-metal. In the presence of the superconductivity surface state become gaped. We have also found that the induced superconductivity have some triplet component along with singlet contribution.

Preprints:

1. Saurabh Pradhan, Sayan Basak and G. Venkateswara Pai, *Magnetic Phase Separation in electron doped manganites,* (in preparation)

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

3. Udit Khanna, Arijit Kundu, Saurabh Pradhan and Sumathi Rao, *Proximity induced superconductivity in Weyl semi-metals,* (in preparation)

Conference/Workshops Attended:

1. *STRONGLY CORRELATED SYSTEMS: FROM MODELS TO MATERIALS*, India, January, 2014

Narayan Rana

Research Summary:

During the last academic year 2013-2014, my work can be divided into two categories.

With Taushif Ahmed, Maguni Mahakhud, Prakash Mathews and V. Ravindran, I worked on calculating next to next to leading order(NNLO) corrections in perturbative Quantum Chromodynamics (QCD) for production of a spin 2 resonance (h) in association with a jet in Large Hadron Collider(LHC). We consider the coupling of h with the Standard Model (SM) fields through the SM energy momentum tensor. Our result is very general in the sense that it can be used to study the production of a jet with missing energy due to KK graviton escaping the detector or a process with resonant massive spin-2 particle in association with a jet. Apart from this, We find that our result correctly exhibits the infrared divergence structure confirming the factorization property of QCD amplitude even for tensorial insertion.

With Taushif Ahmed, Maguni Mahakhud and V. Ravindran, I also worked on soft plus virtual contribution to Drell-Yan production at N^3LO using soft gluon resummation. To test the predictions of the SM and beyond the SM (BSM) theories using various scattering processes, it is inevitable to include the higher order QCD radiative corrections. Also, computation beyond leading order significantly reduce theoretical uncertainities coming from renormalizatin and factorization scales, making the prediction as robust as possible. On the other hand, while calculation of full N^3LO correction to DY production is almost impossible with recent techniques, the soft plus virtual N^3LO corrections have a huge contribution. So, this work is an important step towards precision measurement.

Preprints:

1. Taushif Ahmed, Maguni Mahakhud, Prakash Mathews, Narayan Rana and V. Ravindran, *Two-Loop QCD correction to massive spin-2 resonance $\rightarrow$ 3 gluons* (in preparation) ,

2. Taushif Ahmed, Maguni Mahakhud, Narayan Rana and V. Ravindran, *Drell-Yan production at threshold in N^3LO QCD* (in preparation) .

Conference/Workshops Attended:

1. *CTEQ School on QCD and Electroweak Phenomenology*, University of Pittsburgh, Pennsylvania, USA, July, 2013 ,

2. *Discussion Meeting on Radiative Corrections*, Institute of Physics, Bhubaneswar, India, March, 2014.

Visits to other Institutes:

1. The Institute of Mathematical Sciences, Chennai, India, September 2013.

Arunabha Saha

Research Summary:

We revisit the study of the phase structure of higher spin black holes carried out in arXiv: 1210.0284 using the "canonical formalism". In particular we study the low as well as the high temperature regimes. We show that the Hawking-Page transition takes place in the low temperature regime. The thermodynamically favoured phase changes from conical surplus to black holes and then again to conical surplus as we increase temperature. We then show that in the high temperature regime the diagonal embedding gives the appropriate description. We also give a map between the parameters of the theory near the IR and UV fixed points with the effect that the "good" solutions near IR fixed point map to the "bad" solutions near the UV fixed point and vice versa.

Preprints:

1. Arunabha Saha and Abhishek Chowdhury, *Phase Structure of Higher Spin Black Holes,* arXiv:1312.7017

Conference/Workshops Attended:

1. *National Strings Meet*, India, December 2013,
2. *Workshop on Black Holes and Information Paradox*, India, February 2014.

Visits to other Institutes:

1. Saha Institute of Nucelar Physics, Kolkata, India, June 2013,

Invited Lectures/Seminars:

1. *Phase Structure of Higher Spin Black Holes*, Phase Structure of Higher Spin Black Holes, Indian Institute of Technology Kharagpur, Kharagpur, December 2013.

Akansha Singh

Research Summary:

I have studied the adsorption and diffusion of small silver (n = 1,8) over stepped graphite surface. A silver adatom prefers the missing bridge site of arm-chair step egde. Other small clusters lose their gas phase geometry at the step edge even at 0 K. At finite temperature, atoms in the clusters start diffusing and try to align along the step edge. Depending on the availability of the active sites at steps, deposition of clusters at high temperature leads to the formation of metallic nano-arrays.

In one of my other work, I have studied the absorption of $FeCa_8$ cluster on three differnt type of substrates. $FeCa_8$ is a cluster, which posses atom like properties and called superatom. In gas phase, this cluster has a moment of 4 μ_B. We tried to find to suitable substrate which can preserve the its gas phase properties and and lead toformation of cluster assembled nano materials.

Publications:

1. Akansha Singh,Chiranjib Majumder,and Prasenjit Sen, *Do Agn (up to n = 8) clusters retain their identity on graphite? Insights from first-principles calculations including dispersion interactions,* J. Chem. Phys. **140**, 164705, (2014) .

2. Vikas Chauhan, Akansha Singh, Chiranjib Majumder, Prasenjit Sen, *Structural, electronic and magnetic properties of binary transition metal aluminum clusters: absence of electronic shell structure*, J. Phys. Cond. Matt. **26**, 015006, (2014) .

Preprints:

1. Ajanta Maity, Akansha Singh, Prasenjit Sen, *Peierls transition and edge reconstruction in phosphorene nanoribbons,* arXiv, **1404.2469**, (2014)

2. Akansha Singh and Prasenjit Sen,*Finding the right support for magnetic superatom assembly,* (in preparation)

3. Akansha Singh and Prasenjit Sen, *Diffusion of Ag_n clusters along graphite step edge : Metallic nano arrays*, (in preparation)

Conference/Workshops Attended:

1. *International symposium on Clusters, Cluster Assemblies and Nano-scale Materials*, India, March, 2014

Uttam Singh

Research Summary:

During the academic year 2013-14, I, under the supervision of Prof. Arun Kumar Pati, mainly explored the role of quantum weak measurements at various places in the quantum Information science.

We have defined a measure of quantum correlations based on quantum weak measurement and called it "Super Quantum Discord". This measure captures the role of the observer and the measurement strength in defining the quantum correlations. Using this measure of quantum correlations we have shown that the quantum correlations lost due to the strong (projective) measurement can be resurrected.

Furthermore, we have used remote postselection to realize the weak value associated to an observable in the distant laboratory paradigm using quantum correlation as a resource along with classical communication. We have shown that the quantum correlations can be preserved from degradation due to quantum decoherence arising from a model of noise, namely the amplitude damping channel, using quantum weak measurements.

Publications:

1. Uttam Singh and Arun Kumar Pati, *Quantum discord with weak measurements,* Annals of Physics, **343**, 141-152, (2014).

Preprints:

1. Uttam Singh and Arun Kumar Pati, *Weak measurement induced super discord can resurrect lost quantumness,* arXiv:1305.4393 .

2. Arun Kumar Pati and Uttam Singh, *Weak Values with Remote Postselection and Shared Entanglement,* arXiv:1310.6002 .

3. Uttam Singh, Utkarsh Mishra, and Himadri Shekhar Dhar, *Enhancing robustness of multiparty quantum correlations using weak measurement,* arXiv:1403.2939 .

Conference/Workshops Attended:

1. *13th Asian Quantum Information Science Conference (AQIS'13)* , India, August, 2013.

2. *Meeting on Quantum Information Processing and Applications (QIPA'13)*, India, December, 2013.

3. *International Program on Quantum Information (IPQI'14)*, India, February, 2014.

Invited Lectures/Seminars:

1. *Weak measurement can resurrect lost quantum correlations*, Short Talk, Institute of Mathematical Sciences, Chennai, India, August, 2013.

Other Activities:

1. Served as a tutor for the course of Mathematical Methods 2, January-May, 2014.

Aloke Kumar Sinha

Research Summary:

I am working with my supervisor Dr. Sandhya Choubey. My topic is Direct detectional aspects of Dark matter. The mysterious Dark matter interacts with other matters via gravitational interaction and may interacts also via very feebly other sorts of interactions. These are of course beyond the standard model (SM) of particle physics. One of the familiar candidate for explaining dark matter is supersymmetry.

In direct detection of dark matter, the recoil energy of nucleus of detector is measured and from this mass and strength of interaction of dark matter with nucleus are predicted. Obviously, this is highly model dependent. The recoil energy of nucleus is too small (typically order of kev) and hence it is very difficult to measure it properly. Consequently, conclusion on mass and strength of dark matter with others become extremely erroneous.

One of such direct-detection experiment is DAMA, where NaI was used as detecting material and supersymmetry was taken as possible beyond SM interaction.

I wrote down code for analysing the result of this experiment and with this code, I reproduced the results of DAMA experiment exactly.

Inspired by this exact matching, I used this code, with slight modification, to analyse the results of XENON and LUX (Large Underground Xenon) experiment. I reproduced the results properly.

Then, I started to study self-interacting dark matter. Proper choice of parameter space may put light on new experiments that are going on.

Conference/Workshops Attended:

1. *SERC Main School*, IIT, Kanpur,India, November, 2013.

2. *SANGAM @HRI*, Harish-Chandra Research Institute, Allahabad, India, March, 2014.

Nyayabanta Swain

Research Summary:

The pyrochlore Iridates and Molybdates host various novel phases due to their highly frustrated lattice structure in 3D. The ground state degeneracy of the Ising spins with nearest-neighbour (NN) antiferromagnetic interactions on this lattice is macroscopic, resulting in no magnetic ordering. For classical Heisenberg spins with NN antiferromagnetic interactions the ground state is a classical spin-liquid. The electron-electron interaction scales in these transition series ($4d$ and $5d$) materials are neither negligible nor very large. To understand the effect of moderate interaction strength, especially the Mott-transition, and the short-range correlations, which are prominent in such frustrated system, we have studied the single band Hubbard model on the pyrochlore lattice at half-filling by a real space Monte-Carlo method based on auxiliary fields and have explored the different electronic phases, which can explain the experimental results in a crude way.

With the same method, we have also studied Mott-transition on the checkerboard lattice. This lattice is a 2D analog of the 3D pyrochlore lattice and is also a frustrated one. This lattice shows many interesting magnetic orders, like a spin-glass metal at intermediate interaction strength, a flux like magnetically ordered insulating state which survives till very strong interaction strength in the ground state, apart from the usual paramagnetic metal in the weak interaction limit. At finite temperature the system shows a triangular-lattice like new magnetic ordered phase in the intermediate-strong interaction regime. We have explored the impact of these different magnetic orders and correlations on the electronic phases.

Preprints:

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

Conference/Workshops Attended:

1. *Strongly Correlated Systems: From Models To Materials* , Indian Institute of Science (IISc), Bangalore, India (06-17 January, 2014).

2. *School and Workshop on Physics of Cold Atoms* , Harish-Chandra Research Institute (HRI), Allahabad, India (10-16 February, 2014).

Invited Lectures/Seminars:

1. *Magnetic correlations and Mott transition on the checkerboard optical lattice*, Poster Presentation at the School and Workshop on Physics of Cold Atoms, Harish-Chandra Research Institute, Allahabad, India (15 February, 2014).

2. *Superconductivity, An interesting Phenomenon*, Lectures to Class XI-XII children at the Scientific Workshop by the Rajbhasa Committee, Harish-Chandra Research Institute, Allahabad, India (May, 2013).

Other Activities:

1. Teaching Assistant for the Numerical Methods (NM) course at HRI during Aug-Dec, 2013.

2. Designed the web-page for the event *School and Workshop on Physics of Cold Atoms* at HRI and updated the HRI-Mess web-page.

Sabyasachi Tarat

Research Summary:

I spent this year finalizing my work on disordered superconductors and getting them ready for publication. This consisted of three parts:

1) The 'BCS-BEC' crossover, in which we studied the evolution of superconductivity with increasing coupling strength. We reorganized our previous results, and added a section investigating the behaviour of the spectral function $A(k, \omega)$ in momentum space, comparing the results with state of the art Quantum Monte Carlo methods. We also tightened the final discussion section, explaining the advantages and disadvantages of our method, and readying the final manuscript for publication.

2) The disorder driven Superconductor-Insulator transition: We extended the analysis of this problem, tackling global observables such as transport, spectra and phase diagram in one manuscript, and local signatures in another.

3) Magnetic impurities in Superconductors: We extended the parameter regime of our study, providing a more comprehensive picture of the effect of impurity strength on superconductivity. We also provided a spatial analysis of the local inhomogeneities that are caused by the impurities, examining their thermal evolution in detail.

Publications:

1. Sabyasachi Tarat and Pinaki Majumdar, *Pairing fluctuations, the BCS-BEC crossover and strong disorder in superconductors,* J. Supercond. Nov. Magn. **26**, 1787, (2013)

2. Sabyasachi Tarat and Pinaki Majumdar, *Charge dynamics across the disorder driven superconductor-insulator transition,* Europhys. Lett. **105**, 67002, (2014)

Preprints:

1. Sabyasachi Tarat and Pinaki Majumdar, *A real space auxiliary field approach to the BCS-BEC crossover,* arXiv:1402.0817

2. Sabyasachi Tarat and Pinaki Majumdar, *Tunneling spectroscopy across the superconductor-insulator thermal transition* (in preparation)

3. Sabyasachi Tarat and Pinaki Majumdar, *The effect of magnetic impurities on a moderately strong superconductor* (in preparation)

Conference/Workshops Attended:

1. *Strongly Disordered Superconductors and the Superconductor Insulator Transition*, France, February 2014.

Trilochan Bagarti

Research Summary:

Modelling of low energy ion-sputtered Tantalum surface: I have worked on the kinetic Monte Carlo modelling of self organized nanostructures on Tantalum surface by ion beam sputtering at low energy. This work is in collaboration with the Prof. Shikha Varma's group at Institute of Physics, Bhubaneswar. Experimental results showed that ion sputtering of Tantalum surface produced a ripple pattern. The surface morphology was characterized an it was found that it deviated considerabily from the KPZ class. We have proposed a simple one dimensional model to explain this phenomena.

The trapping reaction diffusion models: The trapping reaction diffusion model in the presence of mutual exclusion has been studied numerically by self Langevin dynamics. This work is in collaboration with Prof. Kalyan Kundu. The survival probability is known to show a stretched exponential behavior. We have shown that when exclusion between the diffusing particles is introduced the stretched exponent is modified.

Trapping reaction with a symmetric double well potential has been studied. This model can be applied to certain ecological processes that involves the spatially inhomogenous predation of a species. We have calculated the survival probability for a double well potential.

Continuing work: We are studing the transport of charge and spin in mesoscopic devices. We have considered a multiterminal mesoscopic device with a Rashba spin orbit interaction in the scattering region which is connected to normal or ferromagnetic leads. A simple analytical model has been developed that captures the essential physics qualitatively. For our study we have used the non-equilibrium Green's function method. In our model we have introduced the contact through the self energy terms that arises due to the contacts. This enables us to calculate the transport coefficients analytically. Furthermore, are studying spin transport through a single level quantum dot system described by the Anderson Hamiltonian. Here we are using the equation of motion technique to understand the nonequilibrium kondo problem.

Preprints:

1. Trilochan Bagarti and Kalyan Kundu, *Asymptotic survival probability of a particle in reaction-diusion process with exclusion in the presence of traps*, arXiv:1310.0093

2. Shalik Ram Joshi, Trilochan Bagarti and Shikha Varma, *Kinetic Monte Carlo simulations of self organised nanostructures on Tantalum surface by low energy ion beam sputtering*(in preparation)

3. Trilochan Bagarti and Kalyan Kundu,*Trapping reaction in a symmetric double well potential*(in preparation)

Visits to other Institutes:

1. IISER, Mohali, India, October 2013.

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

Invited Lectures/Seminars:

1. *A theoretical study of formation of clusters at nanoscale using reaction-diffusion models in one and two dimensions*, Talk, IISER, Mohali, October 2013.

Manabendra Nath Bera

Research Summary:

During the academic year 2013-14, I have worked, as a part of the QIC group, covering several topics. In broader sense, my research works mostly involve deepening the understanding of quantum correlation present in a quantum system and the quantumness i.e., the quantum correlating power of global quantum evolution. We explored how these quantum correlation of states and quantumness of evolution play roles in quantum metrology. We have also investigated the dynamics of quantum correlation in open quantum systems.

We have proposed a new quantum correlation measure for a bipartite quantum system, based on quantum Fisher information. We show that the minimal quantum Fisher information due to local unitary evolution can reliably quantify quantum correlation present in the system. Our measure can directly be exploited to get better insights in quantum metrology, in particular, to investigate how the quantum correlation is instrumental in enhancing metrological precision. Our analysis shows that, for the first time, not only quantum entanglement but also quantum can play decisive

role for better precision. Even, for the separable quantum states with non-zero quantum correlation, one can go beyond standard quantum limit and reach Heisenberg limit. We have extend our study to continuous variable systems. In particular, we have proposed a similar measure of quantum correlation for Gaussian quantum states based on quantum fisher information where the local unitary is composed of the Hamiltonians that are quadratic in canonical operators. As in the case of discrete quantum systems, we again have shown that, quantum correlation can indeed play a constructive role to enhance metrological precisions even in the absence of quantum entanglement. The tighter bounds on the metrological precision are derived both for discrete and continuous variable systems in the presence and absence of quantum correlation.

We have also studied the quantumness of non-local Hamiltonians. We have proposed a quantifier of this quantumness based on quantum Fisher information. We also show that the quantumness of non-local Hamiltonians are responsible for measurement precision in the metrology with global unitary and the product states as the probe states.

Finally we have studied the dynamics of quantum correlation, based on our proposed measure, for open quantum systems. We have also introduced a measure of non-Markovianity in terms of the our quantum correlation measure.

Preprints:

1. Manabendra N Bera , *Quantifying quantum correlation using quantum Fisher information: Delimiting quantum metrology,* (in preparation)

2. Manabendra N Bera, *Quantum Fisher information as the measure of Gaussian quantum correlation: Bounding precision in metrology,* (in preparation)

3. Manabendra N Bera, *Quantifying quantumness of non-local Hamiltonians: roles in quantum metrology,* (in preparation)

4. Manabendra N Bera, Himadri S. Dhar, *Quantifying non-Markovianity via quantum correlation,* (in preparation)

Conference/Workshops Attended:

1. *International program on Quantum Information*, IOP, Bhubaneshwar, India, February, 2014.

Visits to other Institutes:

1. S. N. Bose National Center for Basic Science, Kolkata, India, February, 2014.

Anindya Biswas

Research Summary:

In the academic year "2013-2014", I have worked mainly in the field of quantum information and its interface with many-body physics. I have studied multipartite entanglement in quantum many-body systems and investigated its efficiency in detecting quantum phase transitions. I have investigated the bipartite quantum correlations in the presence of three-spin interactions in quantum spin chains. I have also studied the entanglement spectrum in some non-integrable quantum many-body systems. Apart from these investigations at the interface of many-body physics and quantum information, I have also worked in some other directions. We have introduced a new quantum measure, namely shared purity, for multipartite shared quantum systems. The shared purity is a quantum measure which is different from quantum correlations and can be useful in the identification and quantification of quantum resources in shared quantum systems. I have investigated the decay and in particular, the freezing of information-theoretic bipartite quantum correlations in multiparty shared quantum systems interacting with its environment. I have studied the quantum discord with sandwiched relative entropies. We have evaluated, analytically and numerically, the measure for paradigmatic classes of shared states. We have used the measure to detect the quantum critical point in the transverse quantum Ising model, where we find that the measure can be used to remove an unquieting feature of quantum discord. Furthermore, the measure provides better exponents in finite-size scaling than the ones for other known detectors of the same quantum phase transition. Outside the field of quantum information, I have also studied an empirical law, namely the Benford's law in the context of phase transitions in quantum XY models.

Publications:

1. A. Biswas, A. Sen(De), and U. Sen, *Shared purity of multipartite quantum states,* Phys. Rev. A **89**, 032331, (2014)

2. S.K. Haldar, B. Chakrabarti, T. K. Das, and A. Biswas, *Correlated many-body calculation to study characteristics of Shannon information entropy for ultracold trapped interacting bosons,* Phys. Rev. A 88, 033602, (2013)

Preprints:

1. A.D. Rane, U. Mishra, A. Biswas, A. Sen(De), U. Sen, *Benford's law gives better scale exponents in phase transitions of quantum XY models,* arXiv:1405.2744 [quant-ph]

2. A. Misra, A. Biswas, A. K. Pati, A. Sen(De), and U. Sen, *Quantum Correlation with Sandwiched Relative Entropies,* (in preparation)

3. M.N. Bera, A. Biswas, A. Sen(De), U. Sen, *Quantum Correlations in the presence of Three-Spin Interactions in Quantum Spin Chains* (in preparation)

4. T. Chanda, A.K. Pal, A. Biswas, A. Sen(De), U. Sen, *Decay of Quantum Correlations in Quantum Systems Interacting with its Environment* (in preparation)

Conference/Workshops Attended:

1. *IPQI-2014*, IOP, India, February, 2014.

2. *IMQCILS-2013*, IITJ, India, December, 2013.

3. *QIPA-2013*, HRI, India, December, 2013.

Visits to other Institutes:

1. Bose Institute, Kolkata, India, February, 2014.

2. Bose Institute, Kolkata, India, December, 2013.

3. Kalyani University, Kalyani, India, November, 2013.

Invited Lectures/Seminars:

1. *Shared purity of multipartite quantum states*, IPQI-2014, IOP, Bhubaneshwar, February, 2014.

2. *Quantum correlations and beyond*, IMQCILS-2013, IITJ, Jodhpur, December, 2013.

3. *Shared purity of multipartite quantum states*, QIPA-2013, HRI, Allahabad, December, 2013.

Other Activities:

1. Local organizer, QIPA-2013 at HRI, December, 2013.

2. Academic activities of the group, April-2013 – March-2014.

Arindam Chatterjee

Research Summary:

During the last academic year, my work has been focused on Dark Matter and phenomenology of Supersymmetry.
Recent observations by Fermi-LAT found an excess of monochromatic photon with energy of about 130 GeV. The inclusion of right-chiral sneutrino superfields is a rather straightforward addition to a supersymmetric scenario. A neutral scalar with a substantial right sneutrino component is often a favoured dark matter candidate in such cases. In this context, in [1] we have focused on the tentative signal in the form of a monochromatic photon, which may arise from dark matter annihilation and has drawn some attention in recent times. We studied the prospect of such a right sneutrino Dark Matter candidate in the contexts of both MSSM and NMSSM extended with right sneutrino superfields, with special reference to the Fermi-LAT data. We concluded that annihilation of a pair of right sneutrino Dark Matter could give rise to the photon signal. In [2], we have explored left-sneutrino as an inelastic Dark Matter candidate, and studied the parameter space where it can achieve the right thermal relic abundance.
In recent times, the LHC has generated a huge interest. This motivates us to explore collider signatures of various possible extensions of the Standard Model (SM). I have been working on a few projects [3], on possible

collider signatures of in the context of minimal and next-to-minimal supersymmetric extensions of SM.

Preprints:

1. Arindam Chatterjee, Debottam Das, Biswarup Mukhopadhyaya and Santosh Kumar Rai, *Right Sneutrino Dark Matter and a Monochromatic Photon Line,* arXiv:1401.2527 (*accepted for publication in JCAP*).

2. Arindam Chatterjee, Narendra Sahu, *Resurrecting (left) sneutrino Dark Matter in the light of Neutrino Mass and LUX,* (in preparation),

3. Jyotiranjan Beuria, Arindam Chatterjee, Aseshkrishna Datta, Santosh Kumar Rai, *Signatures of light third generation squarks at LHC,* (in preparation).

Conference/Workshops Attended:

1. *SUSY-DM*, India, October, 2013,

2. *WHEPP*, India, December, 2013.

Visits to other Institutes:

1. ISI, Kolkata, India, August, 2013,

2. IISc, Bengaluru, India, October, 2013.

Other Activities:

1. Refereed a paper for *Physics Letters B*, November, 2013.

Richard Scott Garavuso

Research Summary:

My research in string theory is at the interface of physics and mathematics. I have recently completed a paper [1] concerning Type II string theory in the context of BPS black holes:

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

A paper [2] which considers the case of higher charges is currently in progress. In the future, we plan to extend our analysis to compactifications of Type II string theory on K3 surfaces and Calabi-Yau 3-folds.

I have also been working on mirror symmetry and topological field theory. My most recent paper [3] on this subject concerns analogues of Mathai-Quillen forms; such analogues arise physically in A/2 and B/2 model pseudo-topological field theories:

Abstract: We construct sheaf-cohomological analogues of Mathai-Quillen forms, that is, holomorphic bundle-valued differential forms whose cohomology classes are independent of certain deformations, and which are believed to possess Thom-like properties. Ordinary Mathai-Quillen forms are special cases of these constructions, as we discuss. These sheaf-theoretic variations arise physically in A/2 and B/2 model pseudo-topological field theories, and we comment on their origin and role.

A followup paper [4] which checks supersymmetry in these models is in currently in progress. In the future, we hope to obtain a proof of the Thom-like properties mentioned above. Furthermore, I am working on a paper [5] which studies Mathai-Quillen forms in the context of $\mathcal{N} = 1$ supersymmetric Yang-Mills theories.

Preprints:

1. A. Chowdhury, R. S. Garavuso, S. Mondal and A. Sen, *BPS State Counting in N=8 Supersymmetric String Theory for Pure D-brane Configurations,* arxiv:1405.0412.

2. A. Chowdhury, R. S. Garavuso, S. Mondal and A. Sen, in preparation.

3. R. S. Garavuso and E. Sharpe, *Analogues of Mathai-Quillen forms and applications to topological field theory,* arXiv:1310.5754.

4. R. S. Garavuso and E. Sharpe, in preparation.

5. M. Bochicchio and R. S. Garavuso, *Change to the ASD variables in $\mathcal{N} = 1$ SUSY YM and the Mathai-Quillen form*, in preparation.

Conference/Workshops Attended:

1. *String-Math-2014 Satellite Workshop: Calabi-Yau Manifolds and their Moduli*, University of Alberta, Edmonton, Alberta; Canada, June 14 - 19, 2014.

Invited Lectures/Seminars:

1. *BPS State Counting in N=8 Supersymmetric String Theory for Pure D-brane Configurations*, String-Math-2014, University of Alberta, Edmonton, Alberta; Canada June 9 - 13, 2014

2. *Analogues of Mathai-Quillen forms and applications to topological field theory*, National Strings Meeting, Indian Institute of Technology, Kharagpur, India, 22 - 27 December 2013.

3. *Analogues of Mathai-Quillen forms and applications to topological field theory*, Geometry of Strings and Fields, The Galileo Galilei Institute for Theoretical Physics, Florence; Italy, 26 August - 20 October 2013.

4. *Analogues of Mathai-Quillen forms and applications to topological field theory*, The String Theory Universe, 19th European Workshop on String Theory, AEC Workshop and 1st COST MP1210 meeting, University of Bern, Bern, Switzerland, 2 - 6 September 2013.

Kouhei Hasegawa

Research Summary:

I have researched the Catani-Seymour dipole subtraction procedure. I have especially concentrated on the construction of the practical algorithm to use the procedure. Then I succeeded in the construction of the new algorithm, , called Dipole Splitting algorithm (DSA). I wrote up the paper

about the new algorithm, the preprint number: HRI-P-14-03-001, and submitted the paper to the archive as arXiv:1403.6235. I have also studied the extra dimension model which is continued from the previous work, Phys. Rev. D87(2013)016011. I will publish a paper about the model with my collaborators soon.

Preprints:

1. K. Hasegawa, *Dipole Splitting Algorithm*, arXiv:1403.6235, Preprint number: HRI-P-14-03-001.

Conference/Workshops Attended:

1. *Sangam at HRI 2014*, India, March 2014

Yoshinori Homma

Research Summary:

During the academic year 2013-2014, I studied about two dimensional supersymmetric gauge theories and related mathematical physics.

A few years ago, it was proposed that the Kahler potential on the quantum Kahler moduli space of Calabi-Yau manifold can be computed by the exact partition function of two dimensional supersymmetric sigma model. This means that we can extract nonperturbative corrections for certain backgrounds without using mirror symmetry. Strongly motivated from the string compactification, Calabi-Yau three folds has been studied extensively. In collaboration with Masahide Manabe, I conducted a comprehensive study on the quantum aspects of higher dimensional Calabi-Yau manifolds and we are also trying to generalize this approach to understand more general backgrounds such as super Calabi-Yau manifolds and backgrounds with branes.

Publications:

1. Yoshinori Honma and Masahide Manabe, *Exact Kahler Potential for Calabi-Yau Fourfolds*, Journal of High Energy Physics **05**, 102, (2013)

Preprints:

1. Yoshinori Honma and Masahide Manabe, *Exact Kahler potential for (super) Calabi-Yau manifold* (in preparation)

Conference/Workshops Attended:

1. *National Strings Meeting 2013*, India, December 2013.
2. *KEK Theory Workshop 2014*, Japan, February 2014.

Visits to other Institutes:

1. KEK Theory Center, Ibaraki, Japan, February 2014.

Invited Lectures/Seminars:

1. *Exact Kahler potential for (super) Calabi-Yau manifold*, Poster presentation at "KEK Theory Workshop 2014", KEK, Ibaraki, Japan, February 2014.
2. *Exact Kahler potential for (super) Calabi-Yau manifold*, Technical Talk at "National Strings Meeting 2013", Indian Institute of Technology, Kharagpur, India, December 2013.
3. *Exact Kahler potential for (super) Calabi-Yau manifold*, Seminar, HRI, Allahabad, India, August 2013.

Other Activities:

1. Reviewer, for manuscripts submitted to *International Journal of Modern Physics A*.

Masazumi Honda

Research Summary:

I have joined HRI in the last November. In the five months from Nov. 2013 to Mar. 2014, I have been working on three dimensional supersymmetric gauge theory, which is related to string and M-theory.

First I have shown with Masashi Fujitsuka and Yutaka Yoshida that some supersymmetric quantities in three dimensional $\mathcal{N} = 2$ supersymmetric gauge theory have two equivalent representations in terms of Coulomb and Higgs branch vacua.

Next, I have computed partition function in orbifold ABJM theory with Sanefumi Moriyama and ABJ theory with Kazumi Okuyama, which are expected to be dual to M-theories on certain orbifolds via AdS/CFT correspondence. We have determined non-perturbative structure of the partition function including worldsheet and D-brane instanton effects.

Preprints:

1. Masashi Fujitsuka, Masazumi Honda and Yutaka Yoshida, *Higgs branch localization of 3d N=2 theories,* arXiv:1312.3627 [hep-th]

2. Masazumi Honda and Sanefumi Moriyama, *Instanton Effects in Orbifold ABJM Theory,* arXiv:1404.0676 [hep-th]

3. Masazumi Honda and Kazumi Okuyama, *Exact results on ABJ theory and the refined topological string,* arXiv:1405.3653 [hep-th]

Conference/Workshops Attended:

1. *Quantum Information Processing and Applications (QIPA-2013)*, India, December 2013.

2. *National Strings Meeting 2013 (NSM 2013)*, India, December 2013.

3. *The 8th Asian Winter School on Strings, Particles and Cosmology*, India, January 2014.

4. *Workshop on Black Hole Information Paradox*, India, February 2014.

5. *KEK theory workshop 2014 -Fundamental questions in string theory and quantum field theory-*, Japan, February 2014.

6. *JSPS/RFBR collaboration Workshop Progress in the synthesis of integrabilities arising from gauge-string duality*, Japan, March 2014.

7. *Kavli IPMU-FMSP Workshop Supersymmetry in Physics and Mathematics*, Japan, March 2014.

Visits to other Institutes:

1. Indian Institute of Technology Kharagpur, Kharagpur, India, December 2013,

2. High Energy Accelerator Research Organization (KEK), Tsukuba, Japan, February 2014.

3. Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), Kashiwa, Japan, March 2014.

Invited Lectures/Seminars:

1. *Higgs branch localization of 3d N=2 theories*, National Strings Meeting 2013 (NSM 2013), Indian Institute of Technology Kharagpur, Kharagpur, December 2013.

2. *Higgs branch localization of 3d N=2 theories*, HRI String seminar, Harish-Chandra Research Institute, Allahabad, February 2014.

3. *Exact results on ABJ theory*, KEK theory workshop 2014, KEK, Japan, February 2014.

4. *Higgs branch localization of 3d N=2 theories*, Kavli IPMU Math and String seminar, Kavli IPMU, Japan, February 2014.

5. *Higgs branch localization of 3d N=2 theories*, JSPS/RFBR collaboration Workshop Progress in the synthesis of integrabilities arising from gauge-string duality, Osaka City University, Japan, March 2014.

6. *Higgs branch localization of 3d N=2 theories*, Kavli IPMU-FMSP Workshop Supersymmetry in Physics and Mathematics, The University of Tokyo, Japan, March 2014.

7. *Higgs branch localization of 3d N=2 theories*, KEK Theory seminar, KEK, Japan, March 2014.

8. *Instanton Effects in Orbifold ABJM Theory*, HRI String seminar, Harish-Chandra Research Institute, Allahabad, April 2014.

Madhuparna Karmakar

Research Summary:

Imbalanced Fermi system harbors a particular class of unconventional superfluid phase in which the order parameter changes sign in the *real* space rather than in the *momentum* space. Predicted around four decades ago in the context of superconductors such phases are now classified as the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) phase or modulated superfluid phase. Arising due to finite momentum pairing ($\mathbf{q} \neq 0$) between different electronic species and characterized by a spatially modulated order parameter, such superfluid phases have been recently realized experimentally in ultracold atomic gases, wherein the said imbalance in the population of the different spin species are being created by a Zeeman magnetic field arising due to the difference in the chemical potentials of the corresponding spin species ($h = (\mu_\uparrow - \mu_\downarrow)/2$). Based on the earlier mean field studies the ground state of such system could be broadly segregated as (i) Unpolarized superfluid phase (USF), (ii) Modulated superfluid phase (FFLO) and the (iii) Partially polarized fermi liquid phase (PPFL). Regarding the thermal evolution of these phases, once again the mean field approach to the problem had been used so far which suffers from the drawback of not taking into account the amplitude and phase fluctuations of the order parameter.

In the present work we have addressed the issue of phase transitions in the imbalanced superfluid system, taking into account the effect of amplitude and phase fluctuations of the order parameter. This has been achieved by using a static auxiliary field Monte Carlo technique which trades off the temporal fluctuations for the accessibility to larger system sizes. Retaining the thermal fluctuations enabled us to determine the exact T_c of the phases unlike the mean field approach which leads to gross overestimation of the critical temperature of any phase.

Detailed analysis of the system over the wide $\mu - h$ or $n - h$ space has revealed that the modulated superfluid phase which constitute a part of the ground state phase diagram consists of a plethora of intraphase states depending upon the exact parameter space under consideration. Rise in temperature progressively disorders the state and finally leads to a thermally disordered state in which the amplitude of the order parameter does not vanish identically but the phase coherence between the difference regions of finite amplitude is lost, leading to the loss of global superfluidity of the system, even though the system can still be superfluid locally at

the regions with finite order parameter amplitude. All the inter and intraphase transitions are found to be accompanied by thermal hysteresis.

Preprints:

1. Madhuparna Karmakar and Pinaki Majumdar, *The thermal transition in imbalanced strong coupling superfluids,* (in preparation)

Conference/Workshops Attended:

1. *School and Workshop on Physics of Cold Atoms*, India, February, 2014

Other Activities:

1. Presented poster entitled "Thermal signatures of a population imbalance driven modulated superfluid in an optical lattice" in School and Workshop on Physics of Cold Atoms, HRI, India, February, 2014

Tanumoy Mandal

Research Summary:

During the last academic year, I have worked on various beyond the Standard Model (SM) scenarios including the LHC phenomenology of vectorlike quarks and search for ADD graviton in central diffractive processes at the LHC. Also I have worked in a project where we have developed a method of extracting couplings from off-shell cross-sections at a hadron collider. Here I briefly describe my work.

We present a novel method of extracting the couplings of a heavy particle to the SM states. Contrary to the usual discovery process which involves studying the on-shell production, we look at regions away from resonance to take advantage of the simple scaling of the cross-section with the couplings. We apply the procedure to the case of a heavy quark as an illustration.

We analyze the LHC phenomenology of warped extra dimensional models with Zbb coupling protection and study the LHC signatures of vectorlike quarks with EM charges 1/3, 2/3 and 5/3. In addition to specific model aspects, we also present some results in a model independent way.

We have indicated the possibility of using dilepton and diphoton in the final state to signal the presence of extra dimensions. We found that within reasonable parameter ranges as suggested by present day studies, to use central production, with forward detectors for the proton fragments, to look for KK gravitons as a signal for ADD like theories.

Publications:

1. Rahul Basu, Tanumoy Mandal, *Graviton Signals in Central Production at the LHC,* Adv. High Energy Phys. **652714**, (2013)

Preprints:

1. Baradhwaj Coleppa, Tanumoy Mandal, Subhadip Mitra, *Coupling Extraction From Off-shell Cross-sections,* 1401.4039 [hep-ph]

2. Shrihari Gopalakrishna, Tanumoy Mandal, Subhadip Mitra, Gregory Moreau, *LHC Signatures of Warped-space Vectorlike Quarks,* 1306.2656 [hep-ph]

Conference/Workshops Attended:

1. *Discussion Meeting on EWSB and Flavours in the light of LHC*, Indian Institute of Technology Guwahati, Guwahati, Assam, India (February 20-22, 2014).

2. *Workshop on High Energy Physics and Phenomenology*, Puri, Odisha, India (December 12-21, 2013).

3. *Higgs and Beyond the Standard Model Physics at the LHC*, International Centre for Theoretical Physics, Trieste, Italy (June 24-28, 2013).

4. *ICTP Summer School on Particle Physics*, International Centre for Theoretical Physics, Trieste, Italy (June 10-21, 2013).

Invited Lectures/Seminars:

1. *Vectorlike Quarks at the LHC*, WHEPP-XIII, Puri, Odisha, India (December 18, 2013).

Kenji Nishiwaki

Research Summary:

I give a brief description of my published works. The reference numbers correspond to these in the part "Publications".

- **Collider signals of 5D and various 6D UED models in single-Higgs production channels (Ref. [1]):** The Kaluza-Klein (KK) particles contribute in one-loop leading processes and it is known that, when compared to the case of minimal UED, these result in larger deviations from the Standard Model results. The possible Higgs signals in the golden four-lepton channel, put a bound on UED parameters of KK mass scale and the possible Higgs mass. Following the discovery of the Higgs boson, in **Ref. [1]**, we closely re-evaluated the issue of vacuum stability of the Higgs potential and the constraint from S, T parameters in the 5D minimal UED and its various 6D counterparts. These put stringent bounds on all of them via a global analysis based on the latest LHC data. In this context, we also discussed the prospects of a future photon-photon collider briefly.

- **Proposing new quark flavor models with multiple branes (point interactions) (Ref. [2]):** In collaborations with others, I proposed a new type of quark flavor models by introducing multiple branes (point interactions) in the bulk space. In my previous work, we pointed out that, due to these branes, the zero mode solutions of a 5D fermion field become degenerate and localized and we can derive the required three-generation structure. The origin of the flavor mixing is naturally explained from inevitable overlap of the wavefucntions. After some modifications in the boundary conditions discussed in **Ref. [2]**, the CP phase in the SM can be generated dynamically along with achieving electroweak symmetry breaking and realizing all the quark profiles within 10% accuracy.

- **Ideas to explain the number of matter generation with twisted orbifold in magnetized background (Ref. [3]):** With my collaborators, I proposed new directions where the number of the fermion generations is related to the pattern of twisted orbifold (in **Ref. [3]**) among 2-tori. We classified the possibilities that describe the nature. We found the interesting fact that the twisted orbifolds T^2/Z_3 and T^2/Z_6 cannot be well-defined without the Scherk–Schwarz twist when magnetic flux is introduced. On the orbifolds, zero mode profiles are de-

formed and this observation is expected to be useful in view of flavor physics.

- **Future prospects of double Higgs production at the LHC with general (anomalous) top-Higgs coupling (Ref. [4]):** Double Higgs production at the LHC is fascinating because we can measure the trilinear Higgs self coupling in this channel. With other collaborators, I discussed prospects of their detectability assuming general (anomalous) top-Higgs Yukawa coupling. Some kinematic variables are useful for reducing the background. However, we found that the separability from the backgrounds gets deteriorated after considering 1-loop correction to the background $(pp \to HZ)$.

- **Collider Signature of non-minimal 5D UED model (Ref. [5]):** In a different collaboration, I considered signals in a generalization of the 5D minimal UED model by introducing tree-level brane-localized terms. Due to these terms, some new interactions appear at tree level and the values of the masses of the KK particles can get altered from their minimal UED values. In my previous study which is the first of its kind in such a scenario, we focused on collider signatures of heavy KK excitations from dominant QCD production and found that the LHC would be able to detect some interesting signals when it starts running at higher energies. We pointed out how and to what extent these signatures could fake the minimal UED and/or supersymmetry. We also put a tentative bound on the KK mass scale which can be improved via sophisticated simulation. In **Ref. [5]**, we discussed the detailed situation with the top quark sector of the scenario. After considering the electroweak sector closely, we found some benchmark points where cross sections of the heavy KK top quark production are enhanced. Such enhancements originate from the large effective coupling in (quark)-(quark)-(second KK W/Z boson) interaction. Interestingly, the total decay widths of the second gauge bosons are significantly increased and thus the current bounds are possibly evaded.

Publications:

1. Takuya Kakuda, Kenji Nishiwaki, Kin-ya Oda, and Rroutaro Watanabe,
"*Universal extra dimensions after Higgs discovery*",
Phys. Rev. **D88** 035007 (2013).

2. Yukihiro Fujimoto, Kenji Nishiwaki, and Makoto Sakamoto,
"*CP phase from twisted Higgs vacuum expectation value in extra dimension*",
Phys. Rev. **D88** 115007 (2013).

3. Tomo-hiro Abe, Yukihiro Fujimoto, Tatsuo Kobayashi, Takashi, Miura, Kenji Nishiwaki, and Makoto Sakamoto,
"*Z_N twisted orbifold models with magnetic flux*",
JHEP **1401** 065 (2014).

4. Kenji Nishiwaki, Saurabh Niyogi, and Ambresh Shivaji,
"*ttH Anomalous Coupling in Double Higgs Production*",
JHEP **1404** 011 (2014).

5. AseshKrishna Datta, Kenji Nishiwaki, and Saurabh Niyogi,
"*Non-minimal Universal Extra Dimensions with Brane Local Terms: The Top Quark Sector*",
JHEP **1401** 104 (2014).

Preprints:

1. Yukihiro Fujimoto, Kenji Nishiwaki, and Makoto Sakamoto,
"*CP phase from Higgs's boundary condition*",
Proceedings of Toyama International Workshop on Higgs as a Probe of New Physics 2013 (HPNP2013), 13–16 February 2013, Toyama, Japan, `arXiv:1304.3905 [hep-ph]`.

2. Takuya Kakuda, Kenji Nishiwaki, Kin-ya Oda, Naoya Okuda, and Rroutaro Watanabe,
"*Phenomenological constraints on universal extra dimensions at LHC and electroweak precision test*",
Proceedings of Toyama International Workshop on Higgs as a Probe of New Physics 2013 (HPNP2013), 13–16 February 2013, Toyama, Japan, `arXiv:1304.6362 [hep-ph]`.

3. Takuya Kakuda, Kenji Nishiwaki, Kin-ya Oda, and Rroutaro Watanabe,
"Constraint on Universal Extra Dimensions from scalar boson searches",
Proceedings of Rencontres de Moriond EW 2013, 2–9 March 2013, La Thuile, Italy, `arXiv:1305.1874 [hep-ph]`.

Conference/Workshops Attended:

1. *Workshop on High Energy Physics and Phenomenology (WHEPP13)*, Blue Lily Beach Resort, Puri, Odisha, India, December 12–21, 2013.

2. *Discussion Meeting on EWSB and Flavours in the light of LHC*, Indian Institute of Technology Guwahati, Assam, India, February 20–20, 2014.

3. *SANGAM @ HRI - 2014*, Harish-Chandra Research Institute, Allahabad, India, 24–29 March, 2014.

Visits to other Institutes:

1. Institute of Physics, Bhubaneswar, India, December 2013.

Invited Lectures/Seminars:

1. "*A UED prospect*",
   Short talk in WG-I (Standard Model and Beyond Standard Model Physics at High Energy Colliders) of Workshop on High Energy Physics and Phenomenology (WHEPP13), Blue Lily Beach Resort, Puri, Odisha, India, 16 December 2013.

2. "*Origin of fermion flavor is deciphered by geometry*",
   Seminar talk at Institute of Physics, Bhubaneswar, India, 24 December 2013.

3. "*Prospects of "low-scale" Universal Extra Dimensions*",
   Skype seminar talk at Tata Institute of Fundamental Research, Mumbai, India, 13 January 2014.

Other Activities:

1. Helping the organization of the workshop "SANGAM @ HRI - 2014", March, 2014.

Debraj Rakshit

Research Summary:

During the academic year 2013-14, I started working in the interface of many body physics and quantum information. In particular, my work can

be classified into two main categories: study of disordered spin chains and time dynamics of the many-body systems subjected to sudden perturbation.

I have worked in three different projects that investigate the effect of disorder in the spin models. In the first project, we adopted mean field treatment and investigated the effect of a symmetry breaking unidirectional quenched disorder on the magnetization of the system in classical spin models with continuous symmetry. We numerically simulated disordered models with two- and three-component spins to examine the critical temperature and the behavior of the magnetization as a function of temperature. Moreover, we obtained the analytical expressions for the near-critical scalings of $SO(n)$ n-component spins. We also found that in presence of an additional uniform magnetic field, disorder may enhance the component of magnetization in the direction that is transverse to the disorder field signaling random field induced order. In the second project, we have investigated the quantum characteristics in the random XY and XYZ spin chains. Our results suggest that the quantumness of the bipartite states can be improved significantly by engineering quenched disorder in the system parameters. In the third project, we have covered a substantial parametric regime to examine the ground-state behavior of the magnetization, the classical- and the quantum-correlation functions, and the multipartite entanglement of paradigmatic quantum spin models. Our study signals emergence of disorder induced ordering in certain parametric regimes in all the quantities under study. In the last two projects, we incorporated density matrix renormalization group (DMRG) technique in order to deal with the systems with large number of spins.

Another direction of research that I am currently exploring concerns the time dynamics of quantum correlations of the spin models if the system parameters experience sudden disturbance at a given time. Some analytical and numerical works on the one-dimensional anisotropic XY model have been done. Further works are in progress.

Preprints:

1. Anindita Bera, Debraj Rakshit, Maciej Lewenstein, Aditi Sen(De), Ujjwal Sen, and Jan Wehr, *Classical spin models with broken symmetry: Random Field Induced Order and Persistence of spontaneous magnetization in presence of a random field*, (in preparation).

2. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, Aditi Sen(De),

Ujjwal Sen, *Improving quantum nature by defects in Quantum Spin models*, (in preparation).

3. Utkarsh Mishra, Debraj Rakshit, R. Prabhu, Aditi Sen (De) and Ujjwal Sen, *Constructive Interference Between Disordered Couplings Enhances Multiparty Entanglement in Quantum Spin Models*, (in preparation).

Conference/Workshops Attended:

1. *International Program on Quantum Information (IQPI-2014)*, India, February 2014

Other Activities:

1. Participated in organizing 'International School and Conference on Quantum Information Processing and Applications (QIPA-13)', HRI, Allahabad, December, 2013.

Ambresh Kumar Shivaji

Research Summary:

The Higgs-like scalar discovered at the LHC can be incorporated in many models of new physics which address issues beyond the well established standard model of particle physics. We have considered one such model based on symmetry group $SU(2)_L \times U(1)_Y \times Z_2$ with three $SU(2)$ singlet right handed Dirac neutrinos and two Higgs doublets χ and ϕ. The SM fermions and the Higgs doublet (χ) involving SM Higgs (h) are even under the discrete Z_2 symmetry. The Z_2 symmetry is broken spontaneously by giving a small vev $V_\phi \sim$ eV to the ϕ doublet. The charged Higgs boson $H^\pm$ has practically no coupling with quarks. The main decay modes of the charged Higgs are $H^+ \to l^+\nu_l / W^+\sigma / W^+\rho$, where σ and ρ are other physical Higgs fields in the model, ρ being the pseudoscalar one. The coupling of charged Higgs with a lepton and the corresponding neutrino is $\sim \frac{m_{\nu_l}}{V_\phi}$, that is, it can be large. The charged Higgs branching ratios are very sensitive to the V_ϕ value. If we consider the neutrino oscillation data, the BBN and supernova neutrino constraints on the neutrino Yukawa couplings, we obtain a lower bound on $V_\phi \sim$ KeV. For $V_\phi \sim$ KeV, $H^+ \to W^+\sigma$ is the dominant decay mode. We have performed a complete signal-to-background analysis for the signal $pp \to H^+H^- \to l^+l^- + \not{E}_T$ at the LHC.

We observe that a significance of more than 4σ can be achieved at 14 TeV LHC with 3000 fb^{-1} integrated luminosity.

In the SM, the couplings of the Higgs boson with the top quark is the largest. The presence of new physics may modify both the nature and strength of the top-Higgs coupling. We have studied the effects of anomalous ttH coupling on double Higgs production at the LHC. Like the single Higgs production the gluon-gluon channel (via top quark loop) is the dominant mode to produce double Higgs at the LHC. The signal for the double Higgs production at the LHC is important from the point of view of measuring the trilinear Higgs coupling. Since the anomalous top-Higgs coupling affects both the production and decay of the Higgs boson, we have constrained the parameters of anomalous ttH coupling by performing a global analysis using the available LHC data. We have discussed variation in cross section and in certain kinematic distributions at 14 TeV LHC in presence of the top-Higgs anomalous coupling allowed by the present data. In $pp \to HH \to b\bar{b}\gamma\gamma$ channel, $pp \to HZ$ is one of the main backgrounds. Due to anomalous ttH coupling the HZ production at one-loop via gluon fusion is also affected. We find that this effect is quite large in this case.

The existence of the standard model Higgs boson appears to be a reality, however, there is no clear indication of any new physics in the data analyzed so far by the LHC experiments. Since the effects of new physics are expected to be small, we require precise standard model predictions for various observables along with their precise measurements at the LHC. In this regard, one would also like to consider processes involving the recently discovered Higgs boson to study its coupling with gauge bosons. We aim at computing the NLO QCD correction to the associated production of the Higgs boson with a pair of electroweak vector bosons at the LHC.

Publications:

1. Pankaj Agrawal, Subhadip Mitra and Ambresh Shivaji, *Effect of Anomalous Couplings on the Associated Production of a Single Top Quark and a Higgs Boson at the LHC,* JHEP **12**, 077, (2013)

2. Ushoshi Maitra, Biswarup Mukhopadhyaya, S. Nandi, Santosh Kumar Rai, Ambresh Shivaji *Searching for an elusive charged Higgs at the Large Hadron Collider,* PRD **89**, 055024, (2014)

Preprints:

1. Kenji Nishiwaki, Saurabh Niyogi and Ambresh Shivaji, , *ttH Anomalous Coupling in Double Higgs Production,* arXiv: 1309.6907 [hep-ph]

Conference/Workshops Attended:

1. *Workshop on High Energy Physics Phenomenology XIII* , India, December 2013,
2. *Discussion Meeting on Radiative Corrections* , India, March 2014,
3. *Sangam @ HRI* , India, March 2014.

Visits to other Institutes:

1. Institute of Physics, Bhubaneswar, India, April 2013.
2. Institute of Physics, Bhubaneswar, India, Feb-Mar 2014.

Namrata Shukla

Research Summary:

Fundamental concepts of quantum information and computation were learnt with the help of books and review papers. It includes the study of quantum bits and gates, relevant linear algebra, quantum measurements and Bell inequality. The applications of these concepts in different protocols in quantum communication and quantum computation were also studied. Specific topics studied include quantum entanglement & its applications in quantum information and the behaviour of geometric phase in different quantum systems. Two different projects on these topics are in progress. These projects are on geometric phase and entanglement distillation, and are to be reported soon.

Preprints:

1. A.Kumar, N.Shukla, A.K.Pal and U.Sen, *Quantum Distillation of Entangled States,* in preparation.

Conference/Workshops Attended:

1. *International Program on Quantum Information*, India, February, 2014.

Visits to other Institutes:

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

Other Activities:

1. Delivered lectures on 'Quantum mechanics' and 'Electromagnetic theory of Light' to 11th and 12th standadrd students in the 'Hindi workshop' at the institute, May 26, 2014 and May 28, 2014.

Tomohisa Takimi

Research Summary:

During the period April 2013 to March 2014, I had studied Chern-Simons matter gauge theories. Particularly, I explored evidence for the duality relationship between the Chern-Simons matter theories coupled to the fundamental fermions and the theories coupled to fundamental bosons. In my works, I have calculated the free energy of the both theories, and see the matching of them under the duality mapping, which is deeply related to the level-rank duality of the pure Chern-Simons theory.

Publications:

1. Tomohisa Takimi *Duality and Higher Temperature Phases of Large N Chern-Simons Matter Theories on $S^2 \times S^1$*, JHEP **1307**, 177, (2013)

2. Sachin Jain, Shiraz Minwalla, Tarun Sharma, Tomohisa Takimi, Spenta R. Wadia, Shuichi Yokoyama, *Phases of large N vector Chern-Simons theories on $S^2 \times S^1$*, JHEP **1309**, 009, (2013)

Conference/Workshops Attended:

1. *KIAS-YITP Joint workshop 2013*, Japan, July 2013

2. *National Strings Meeting 2013*, India, December 2013.

Visits to other Institutes:

1. Hokkaido University, Sapporo, Japan, Jul. 2013,
2. IPMU, Kashiwa, Japan, Jul. 2013,
3. Nagoya University, Nagoya, Japan, Jul. 2013.
4. Osaka University, Osaka, Japan, Jul. 2013.
5. Kyoto University, Kyoto, Japan, Jul. 2013.
6. YITP, Kyoto, Japan, Jul. 2013.
7. University of Tokyo, Tokyo, Japan, Jul. 2013.
8. KEK, Tsukuba, Japan, Jul. 2013.
9. TIFR, Mumbai, India, Oct. 2013.
10. TIFR, Mumbai, India, Nov. 2013.
11. IIT Bombay, Mumbai, India, Nov. 2013.

Invited Lectures/Seminars:

1. *Phase structures of Chern-Simons matter theories on* $S^2 \times S^1$, IIT Bombay Physics Department seminar, Physics Department IIT Bombay, IIT Bombay Mumbai, November 2013.
2. *Phase structures of Chern-Simons matter theories on* $S^2 \times S^1$, Tea-duality, Department of Theoretical Physics, TIFR, TIFR, Mumbai, India, October 2013.
3. *Phase structures of Chern-Simons matter theories on* $S^2 \times S^1$, STRINGS AND FIELDS GROUP SEMINAR, String theory group KEK, KEK, Tsukuba, Japan, July 2013.
4. *Phase structures of Chern-Simons matter theories on* $S^2 \times S^1$, Hongo High Energy Physics Theory Group seminar, University of Tokyo, University of Tokyo, Tokyo, Japan, July 2013.
5. *Phase structures of Chern-Simons matter theories on* $S^2 \times S^1$, YITP seminar, YITP, YITP, Kyoto, Japan, July 2013.

6. *Phase structures of Chern-Simons matter theories on $S^2 \times S^1$*, Theoretical Particle Physics Group seminar, Kyoto University, Kyoto University, Kyoto, Japan, July 2013.

7. *Phase structures of Chern-Simons matter theories on $S^2 \times S^1$*, Theoretical Particle Physics Group seminar, Osaka University, Osaka University, Osaka, Japan, July 2013.

8. *Phase structures of Chern-Simons matter theories on $S^2 \times S^1$*, String Group seminar, Nagoya University, Nagoya University, Nagoya, Japan, July 2013.

9. *Phase structures of Chern-Simons matter theories on $S^2 \times S^1$*, IPMU seminar, IPMU, IPMU, Kashiwa, Japan, July 2013.

10. *Phase structures of Chern-Simons matter theories on $S^2 \times S^1$*, Theoretical Particle Physics Group seminar, Hokkaido University, Hokkaido University, Sapporo, Japan, July 2013.

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 Tijdeman: Mathematical Theory of Discrete Tomography.

Mathematics Talks and Seminars

1. Kaushal Verma: Introduction to Complex Dynamical Systems.
2. Sachin Sharma: The T-analog of the Basic String Function for Twisted affine Lie algebras.
3. Carla Farsi: Orbifolds and there invariants.
4. Carlo M Scoppola: Pro-p groups.

Mathematics Colloquia

1. Carla Farsi: Group Actions: a Bridge between Geometry, Algebra and Analysis.
2. S. Eswara Rao: Classification of irreducible, integrable modules for the full toroidal Lie algebras.
3. Shrawan Kumar: Hermitian eigenvalue problem and its generalization to any semisimple group: A survey.
4. Silvio Dolfi: Character degrees and conjugacy class sizes of finite groups.
5. Ramesh Sreekantan: Algebraic Cycles and the Fundamental Group.

Physics Talks and Seminars

1. Richard Garavuso: Deformed mathai-quillen forms in A-twisted (0,2) landau-ginzburg models.
2. Vikram Vyas: Heavy-Quark potential: Shadows of five dimensions.
3. Amit Dutta: The Ground State Quantum fidelity; and indicator of quantum criticality.
4. Rakibur Rahman: Holographic Constraints On A Vector Boson.
5. Debajyoti Sarkar: Blackhole Information at the correspondence point.
6. Roji Pius: Simplest Gauge String Duality.
7. Abhishek Chowdhury: Black Hole Bound State Metamorphosis.
8. Swapnamay Mondal: Black Hole State counting and supersymmetric quantum mechanics.
9. Mehendi Masud: Study of Different detector configuarations in long base line neutrino experiment (LBNE).
10. Matan Field: Low-Energy Effective actions from Holography.
11. Ayan Mukhopadhyay: Spacetime emergence via holographic RG flow from incompressible Navier-stokes at the horizon.
12. Ayan Mukhopadhyay: Generalized landu-Silln theory and Boltzmann-Vlasov equations for semi-holographic non-Fermi liquids.
13. Arnub Rudra: Degeneration of two loop superstring scattering amplitude.
14. Arunabha Saha: Black Holes in 3D higher Spin gravity.
15. Masahide Manabe: Stringy Instanton Counting and Topological Strings.
16. Yoshinori Honma: Kahler Potential for (super) Calabi-Yau Manifold.
17. Swapnamay Mondal: Extinguishing Fire at the event horizon!.
18. Swapnamay Mondal: Extinguishing Fire at the event horizon!.
19. Siddarth Dwivedi : Forward and inverse algorithms.

20. Arindam Chatterjee: Right-handed sneutrino Dark Matter and the 135 GeV γ ray line.

21. Siddharth Dwivedi: Brance Tiling.

22. MIlind Shyani: 2D Blackholes and the Information Problem.

23. Preeda Patcharamaneepakorn: Travelling Front of a Decaying Brane.

24. Justin David: Structure Constants of Beta deformed super Yang-Mills.

25. Animesh Chatterjee: Study of Octant degeneracy resolution and CPT violation with large magnetized iron calorimeter detector (ICAL).

26. Justin David: Renyi entropies of free bosons on torus and holography.

27. Deepak Tiwari: Indirect searches of Dark Matter signatures at INO.

28. Richard Garavuso: Analogues of Mathai-Quillen forms in Sheaf cohomology and applications to topological field theory.

29. Bobby Ezhuthachan: Giant gravitions in AdS$4 \times S7/Z_k$.

30. Ambresh Shivaji: The effects of top-Higgs anomalous coupling in double Higgs production.

31. Trilochan Bagarti: On spin Transport and The Trapping of classical particles.

32. Roji Pius: Mass Renormalization in String Theory.

33. Adeline Crpieux: Current fluctuations and thermoelectricity in interacting/coupled nano-systems.

34. P. S. Burada: Passive and active transport.

35. Mireille Lavagna: Interacting quantum dots under nonequilibrium condition.

36. Brajesh Gupt: Non-singular AdS-dS transitions in a landscape scenario.

37. Kaustubh Deshpanday: Holographic Schwinger effect and critical electric field strength.

38. Sovan Chakraborty: Probing Lorentz invariance violation with the iceCube PeV neutrinos.

39. Arijit Saha: Transport Signatures of fractional fermions in nanowires.

40. Deepak Dhar: Understanding 1/f noise.

41. Vatsal Dwivedi: A kinetic Theory approach to Gauge anomalies.

42. Arjun Menon: Searching for neutral Higgs bosons in non-standard channels.

43. Katri Huitu: Spontaneous R-parity and/or CP violation in NMSSM with right handed neutrinos.

44. Mariana Frank: Charginos and Neutralinos beyond MSSM.

45. Durga Prasad Roy: Why LHC?.

46. Abhishek Sadhukhan: Semiclassical folded spinning string in AdS_3.

47. Masazumi Honda: Higgs branch localization of 3-D $N = 2$ theories.

48. Durga Prasad Roy: Determination of the third mixing angle $theta_13$ and its implications.

49. Durga Prasad Roy: Phenomenology of nonuniversal Gaugino mass models.

50. Ashiwin S. Panday: KK-Momopoles: A study using topological T-Duality.

51. Tomohisa Takimi: Phase structure of the large N Chern-Simons matter theories in the fundamental representation on $S^2 times S^1$.

52. Arpan Bhattacharya: Holographic entanglement entropy.

53. Sven Krippendorf: Phenomenology with D-branes at singularities in type IIB string compactifications.

54. Ram Lal Awasthi: Beyond Standard Model Physics: A non-SUSY grand unification perspective.

55. Arunabha Saha: Thesis Synopsis talk .

56. Sachin Jain: Scattering in Chern simons theories with fundamental matter.

Physics Colloquia

1. Aseem Paranjape: Counts clustering and Collapse: Analytical Methods for large scale structures.
2. Amit Dutta: Quench dynamics of Edge States in 2-D topological insulator ribbons.
3. Surajit Paul: A phenomenological Study on the evaluation of thermal and non-thermal energy in the forming large scale structures of the universe.
4. Manas K Patra: Probing the reality of the quantum state.
5. Biplob Bhattacharjee: Prospects and challenges for BSM search in the era of post Higgs discover.
6. Bruce Mellado: The Discovery of a Higgs boson at the LHC and future prospects.
7. K Rajibul Islam: Quantum simulation of interacting many body systems with cold atoms.
8. Sovan Chakraborty: Supernovae Neutrinos: Challenges and opportunities.
9. Arjun Menon: SUSY In light of the 8TeV LHC.
10. Subhadeep Mitra: Vector-Like Quarks in the Warped-Space Models.
11. Jaydeep Sau: Non-Abelien Majorana modes at generic spin-orbit coupled semiconductor/superconductor interfaces.
12. Boris Kayser: Neutrinos get under your skin.

Recent Graduates

1. **Karam Deo Shankhadhar**, *On certain correspondences between Jacobi forms and modular forms, and a non-vanishing result for half-integral weight L-functions*.

2. **Sourav Mitra**, *Physics of Cosmological Reionization and Structure Formation in the Universe*.

3. **Vijay Sohani**, *Nonlinear Schrodinger Equation and the twisted Laplacian*.

Publications

Publications (Mathematics)

Sukumar Das Adhikari

1. Sukumar Das Adhikari, *An extremal problem in combinatorial number theory*, Proceedings of an International Conference in Celebration of the 125th Anniversary of Ramanujan's Birth; University of Delhi, 17-22 December 2012, (Eds. Bruce C. Berndt and Dipendra Prasad), 1–11, Ramanujan Mathematical Society Lecture Notes Series, Number 20, (2013).

2. Sukumar Das Adhikari, *Schur's theorem in combinatorial number theory: Some generalizations,* J. Indian Math. Soc. (Special Volume) 1–10 (2013).

3. Sukumar Das Adhikari, Weidong Gao and Guoqing Wang, *Erdős-Ginzburg-Ziv theorem for finite commutative semigroups,* Semigroup Forum, To appear, Published online on 14 November 2013.

4. Sukumar Das Adhikari and Eshita Mazumdar, *Modifications of some methods in the study of zero-sum constants,* Integers, To appear.

Ramakrishnan B.

1. B. Ramakrishnan and Karam Deo Shankhadhar, *On the restriction map for Jacobi forms,* Abh. Math. Semin. Univ. Hamburg **83**, 163–174, (2013)

2. B. Ramakrishnan, *Modular forms of half-integral weight,* The Mathematics Student **81**, 101–114, (2012)

Punita Batra

1. S. Eswara Rao, Punita Batra and Sachin S. Sharma, *The irreducible modules for the derivations of the rational quantum torus,* J. of Algebra **410**, 333-342, (2014).

Kalyan Chakraborty

1. K. Chakraborty, S. Kanemitsu and T. Kuzumaki*On the class number formula of certain real quadratic fields,* Hardy-Ramnujan journal **36**, 1–7, (2013)

2. K. Chakraborty, S. Kanemitsu and T. Kuzumaki*On the Barnes multiple gamma functions,* Siauliai Math. Sem., (2014)

Manoj Kumar

1. Manoj K. Yadav, *On subgroups generated by small classes in finite groups,* Comm. Algebra **41**, 3350 - 3354, (2013)

2. Manoj K. Yadav, *On finite p-groups whose central automorphisms are all class preserving,* Comm. Algebra **41**, 4576 - 4592, (2013)

3. Vivek K. Jain, Pradeep K. Rai and Manoj K. Yadav, *Finite p-groups with abelian automorphism group,* Internat. J. Algebra Comput **23**, 1063 - 1077, (2013)

D. Surya Ramana

1. P. Akhilesh and D.S. Ramana, *A Chromatic Version of Lagrange's Four Squares Theorem,* to appear in Monatshefte für Mathematik, 2014.

2. D.S. Ramana, *Representation of Integers as Chromatic Sums of Primes,* Proceedings of the Conference Legacy of Ramanujan, Lecture Notes in Mathematics, Ramanujan Math. Soc., No. 20, pp. 335-346, 2013.

Hemangi Saha

1. Hemangi M Shah, *A new proof of the theorem: harmonic manifolds with minimal horospheres are flat,* Proc. Indian Acad. Sci (Mathematical Sciences), (to appear), (2014).

R. Thangadurai

1. K. Senthil Kumar, R. Thangadurai and M. Waldschmidt, *Liouville numbers and Schanuel's Conjecture*, Arch. Math. (Basel), **102**, 59-70, (2014)

2. M. Ram Murty and R. Thangadurai, *On the parity of the fourier coefficients of j-function*, *To appear in:* Proc. Amer. Math. Soc. (Series A).

3. R. Thangadurai and K. Viswanadham, *On the prime k-tuple conjecture*, *To appear in:* Integers.

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

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

6. S. Subburam and R. Thangadurai, *On the Diophantine equation $x^3 + by + 1 - xyz = 0$*, *To appear in:* C. R. Math. Acad. Sci. Soc. R. Can.

Satya Deo

1. Satya Deo, *Index of a finitistic space and a generalization of the topological central point theorem,* Journal of Ramanujan Mathematical Society **28**, 223-232, (2013)

2. Satya Deo, *Combinatorial 8-manifolds like projective plane and their non-embeddings,* New Zealand J. Mathematics, (2013).

3. Satya Deo, *Topological Combinatorics-Kneser Conjecture,* Mathematics Student, **83**, 01-16, (2014).

4. Satya Deo, *Topological Combinatorics- Tverberg theorem and generalizations,* Clifford Analysis, Clifford Algebra and Applications, (2014)

Debika Banerjee

1. Debika Banerjee and Jay G Mehta, *Linearized product of two Riemann Zeta functions*, To appear in in Proc. of Japan Acad. Sci..

Pallab Kanti Dey

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 (2014).

Kasi Viswanadham G

1. Jay Mehta and G. K. Viswanadham, *Quasi uniqueness of the set of Gaussian prime plus ones,* To appear in International Journal of Number Theory.

2. R. Thangadurai and G. K. Viswanadham, *On prime $k-$tuple conjecture,* To appear in Integers.

Senthil Kumar K

1. K. Senthil Kumar, R. Thangadurai and M. Waldschmidt, *Liouville numbers and Schanuel's conjecture,* Arch. Math. **102**, 59–70, (2014)

2. K. Senthil Kumar, R. Thangadurai and M. Waldschmidt, *Liouville numbers, Liouville sets and Liouville fields*, To appear in Proc. Amer. Math. Soc.

Eshita Mazumdar

1. Sukumar Das Adhikari and Eshita Mazumdar, Modification of Some Methods in the Study of Zero Sum Constants. *Integers* , 14, paper A 25, (2014).

Jay Gopalbhai Mehta

1. Jay G Mehta and G.K. Viswanadham, *Quasi uniqueness of the set of "Gaussian prime plus one's"*, To appear in Internation Journal of Number Theory, Nov., (2014)

Bhavin K. Moriya

1. B. K. Moriya, *On weighted zero sum subsequences of short length,* Integers **14**, A21, (2014).

Akhilesh P

1. P. Akhilesh and D.S. Ramana, *A Chromatic Version of Lagrange's Four Squares Theorem*, To appear in: Monatshefte fur Mathematik

Publications (Physics)

Anirban Basu

1. Anirban Basu, *The structure of the R^8 term in type IIB string theory,* Class.Quant.Grav. **30**, 235028, (2013)

Jayanta Kumar Bhattacharjee

1. J K Bhattacharjee and U Kaatze, *Fluctuations near the critical micelle concentration I. Premicellar aggregation,relaxation rate and isentropic compressibility*, J.Phys Chem **B117** 3790(2013)

2. J K Bhattacharjee and U Kaatze,*Fluctuations near the critical micelle concentration II.Ultrasonic attenuation and spectrum*, J. Phys Chem **B117** 3798 (2013)

3. B Agarwalla,S Galhotra and J K Bhattacharjee, *Diffusion driven instability to a drift driven one : Turing patterns in the presence of an electric field*, J Math Chem DOI **10.1007/S10910-013-0254-4** (2013)

4. S Galhotra, J K Bhattacharjee and B Agarwalla, *Turing -Hopf instabilities through a combination of diffusion, advection and drift*, J Phys Chem **140** 024501 (2014)

5. N Sarkar,A Basu, J K Bhattacharjee and A K Ray, *Acoustic horizons in steady spherically symmetric nuclear fluid flows*, Phys Rev **C88** 055025 (2013)

6. H Pharasi,K Kumar and J K Bhattacharjee, *Entropy and energy spectra in low prandtl number convection with rotation*, Phys Rev **E89** 023009 (2014)

7. D Das, D Banerjee and J K Bhattacharjee, *Supercritical and subcritical Hopf bifurcations in two and three dimensions*, Nonlinear Dynamics DOI **10.1007/s11071-014-1282-8** (2014)

Tapas Kumar Das

1. Neven Bilić, Arpita Choudhary, Tapas K Das & Sankhasubhra Nag, *The role of axisymmetric flow configuration in the estimation of the analogue surface gravity and related Hawking like temperature,* Classical & Quantum Gravity **31**, Issue 3, article id. 035002, (2014)

AseshKrishna Datta

1. Aseshkrishna Datta, Kenji Nishiwaki, Saurabh Niyogi, *Non-minimal Universal Extra Dimensions with Brane Local Terms: The Top Quark Sector,* JHEP **1401**, 104, (2014).

Aditi Sen De

1. U. Mishra, A. Sen(De), and U. 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. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Exclusion principle for quantum dense coding,* Phys. Rev. A **87**, 052319 (2013)

3. 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,* Phys. Rev. A **87**, 052318 (2013).

4. K.R.K. Rao, H. Katiyar, T.S. Mahesh, A. Sen(De), U. Sen, and Anil Kumar, *Multipartite quantum correlations reveal frustration in a quantum Ising spin system,* Phys. Rev. A **88**, 022312 (2013)

5. H.S. Dhar, A. Sen(De), and U. Sen, *Characterizing Genuine Multisite Entanglement in Isotropic Spin Lattices,* Phys. Rev. Lett. **111**, 070501 (2013)

6. R. Prabhu, A. Sen(De), and U. Sen, *Genuine multiparty quantum entanglement suppresses multiport classical information transmission,* Phys. Rev. A **88**, 042329 (2013)

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

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

9. R. Prabhu, A. Sen(De), and U. Sen, *Nonergodic classical correlations lead to ergodic quantum correlations in low-dimensional spin models,* Europhys. Lett. **102** 30001 (2013)

10. A. Sen(De) and U. Sen, *Virtual-site correlation mean field approach to criticality in spin systems,* Phys. Lett. A **377**, 1832 (2013)

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

Raj Gandhi

1. V. Barger, A. Bhattacharya, A. Chatterjee, R. Gandhi, D. Marfatia and M. Masud, *Configuring the Long-Baseline Neutrino Experiment* Phys. Rev. D **89**, 011302 (2014) [arXiv:1307.2519 [hep-ph]].

2. A. Bhattacharya, R. Gandhi and S. Mukhopadhyay, *Re-analysing the implications of CPT and unitarity for baryogenesis and leptogenesis* Phys. Rev D, to appear. arXiv:1109.1832 [hep-ph].

3. K. Bora, D. P. Roy, R. Gandhi, D. K. Chodhury, N. N. Singh, N. Sinha, M. P. Bora and A. A. Sen, *Proceedings, National Conference on Contemporary Issues in High Energy Physics and Cosmology (NC-HEPC 2013) : Gauhati, India, February 12-14, 2013* J. Phys. Conf. Ser. **481** (2014).

Rajesh Gopakumar

1. M. Gaberdiel and R. Gopakumar, *Large N=4 Holography*, JHEP **1309**, 036 (2013).

2. M. Gaberdiel, R. Gopakumar and M. Rangamani, *The Spectrum of Light States in Large N Minimal Models*, JHEP **1401**, 116 (2014).

Anshuman Maharana

1. M. Cicoli, J. Conlon, Anshuman Maharana, F. Quevedo
A Note on the Magnitude of the Flux Superpotential, JHEP, 1401 (2014) 027

Pinaki Majumdar

1. Subrat Kumar Das, Viveka Nand Singh, and Pinaki Majumdar, *Magnon spectrum in the domain ferromagnetic state of antisite-disordered double perovskites,* Phys. Rev. B 88, 214428 (2013).

2. Sanjoy Datta, Viveka Nand Singh, and Pinaki Majumdar, *Radio-frequency spectroscopy of the attractive Hubbard model in a trap,* Phys. Rev. A 89, 053609 (2014).

3. Sabyasachi Tarat and Pinaki Majumdar, *Charge dynamics across the disorder-driven superconductor-insulator transition*, Europhys. Lett., 105 (2014) 67002.

4. Viveka Nand Singh and Pinaki Majumdar, *Huge positive magnetoresistance in antiferromagnetic double perovskite metals*, J. Phys. Cond Mat (in press).

Biswarup Mukhopadhyaya

1. Avinanda Chaudhuri, Walter Grimus, Biswarup Mukhopadhyaya, *Doubly charged scalar decays in a type II seesaw scenario with two Higgs triplets,* JHEP **1402**, 060, (2014)

2. Biswarup Mukhopadhyaya, Somasri Sen, Soumitra SenGupta, *Matter-Gravity Interaction in a Multiply Warped Braneworld,* J. Phys. **G40**, 015004, (2013)

3. 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,* JHEP **1310**, 221, (2013)

4. Nishita Desai, Ushoshi Maitra, Biswarup Mukhopadhyaya, *An updated analysis of radion-higgs mixing in the light of LHC data ,* JHEP **1310**, 093, (2013)

5. Shankha Banerjee, Satyanarayan Mukhopadhyay, Biswarup Mukhopadhyaya, *Higher dimensional operators and LHC Higgs data : the role of modified kinematics,* Phys. Rev. **D89**, 053010, (2014)

6. Ushoshi Maitra, Biswarup Mukhopadhyaya, S. Nandi, Santosh Kumar Rai, Ambresh Shivaji, *Searching for an elusive charged Higgs at the Large Hadron Collider,* Phys. Rev. **D89**, 0555024, (2014)

Arun Kumar Pati

1. I. Chakrabarty, A. K. Pati, P. Agrawal, *CTC assisted PR box type correlation can lead to signaling*, Quantum Information and Computation, **14**, 1251 (2014).

2. U. Singh and A. K. Pati, *Quantum Discord with Weak Measurements*, Annals of Phys. **343**, 141 (2014).

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

Santosh Kumar Rai

1. U. Maitra, B. Mukhopadhyaya, S. Nandi, Santosh Kumar Rai and A. Shivaji, *Searching for an elusive charged Higgs at the Large Hadron Collider,* Phys. Rev. D **89**, 055024, (2014). [arXiv:1401.1775 [hep-ph]].

2. S. Banerjee, M. Frank and Santosh Kumar Rai, *Higgs data confronts Sequential Fourth Generation Fermions in the Higgs Triplet Model,* Phys. Rev. D **89**, 075005, (2014). [arXiv:1312.4249 [hep-ph]].

3. K. S. Babu, A. Patra and Santosh Kumar Rai, *New Signals for Doubly-Charged Scalars and Fermions at the Large Hadron Collider,* Phys. Rev. D **88**, 055006, (2013).

4. S. Chakdar, K. Ghosh, S. Nandi and Santosh Kumar Rai, *Collider signatures of mirror fermions in the framework of a left-right mirror model,* Phys. Rev. D **88**, 095005, (2013).

Sumathi Rao

1. Udit Khanna, Saurabh Pradhan and Sumathi Rao, *Transport and STM studies of hyperbolic surface states of topological insulators*, Phys. Rev. **B87**, 245411, (2013)

Ashoke Sen

1. A. Sen, "S-duality Improved Superstring Perturbation Theory," JHEP **1311** (2013) 029 [arXiv:1304.0458 [hep-th]].

2. J. Manschot, B. Pioline and A. Sen, "Generalized quiver mutations and single-centered indices," JHEP **1401** (2014) 050 [arXiv:1309.7053 [hep-th]].

Prasenjit Sen

1. A. Singh, C. Majumder and P. Sen, *Do Ag_n (up to $n = 8$) clusters retain their identity on graphite? Insights from first-principles calculations including dispersion interactions,* J Chem. Phys. **140**, 164705, (2014)

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Computer Section

1. All the important packages were upgraded on the servers such as Mail, Webmail, DNS, SSH, DHCP, Proxy, LDAP and Firewall for the better, reliable and secure performance.

2. Newer versions of different flavors of Linux operating systems were upgraded on the desktops.

3. New versions of several applications softwares and packages were loaded on users' systems, computer centre systems and conference room systems, which provided the researchers to do their numerical and analytical calculations faster and obtain more precise results.

4. Computing related to conferences were held in the conference computer room.

5. Two split ACs were installed in the UPS room.

6. The Internet bandwidth was also substantially upgraded to 150 Mbps so that online access to the journals subscribed by HRI can be downloaded quickly.

7. Tendering process has been initiated for the purchase of 20 desktop computers for Ph.D. students.

8. Tendering process has been initiated for upgrading the entire campus-wide network to increase accessibility, speed, and the reliability.

9. Tendering process has been initiated for the replacement of old SMF batteries for the centralised online UPS systems.

Current activities and plans

1. Purchase of 20 desktops for Ph.D. students is being initiated.

2. Up-gradation of the numerical softwares, Mathematica and Matlab, with several new features, which will help the researchers to carry out their calculations with more advanced techniques.

Library

The Institutes library is one of the best-equipped libraries in the region. Being the library of a research institute, it provides the required support to the academic and research activities. It remains open on all working days from 8 am to 2 am including Saturdays. It also remains open during the Sundays and the Gazzetted holidays from 10 a.m. to 6 p.m. It has added 304(Three hundred and four) books including 78 gifted books to its fold. It increased the total number of books to 21154 (Twenty one thousand one hundred and fifty four) which includes 1077 gifted books. It has also added 201 bound volumes of the journals during the period from 1st April 2013 to 31st March 2014. It has increased its bound volume collection to 35420. The institutes library has a total collection of 56574 (Fifty six thousand and five hundred seventy four) books and bound volumes. The library has subscribed to 178 journals during this period. This includes 96 online journals.

During the current year we have procured or added the Archives of Springer in Mathematics and Statistics, American Institute of Physics (AIP) Archives, IOP (Institute of Physics) Archives too in our collection.

The physical stock verification has been recently completed with the help of PDT (Portable Data Terminal) for collection of Bar Codes. The whole collection is Bar Coded and equipped with Tattle Tapes for security. It reflected no loss of any title in the category of books or journals.

Our library is facing a lot of space problem. As we know that the library is a growing organism the need for space is increasing accordingly. We had already planned for 2.5 folds increase of our present space. The construction of the same is also in the full swing which will allow the library space increase horizontally. Recently we have provided the latest systems to our users for browsing the library OPAC and related search. We enriched our Digital Library Depository of the HRI, which includes 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 on line. We have been providing on-line access of periodicals to our users for 96(Ninety six) titles. We have provided the Web Enabled library catalogue to our users. The library can be termed as a completely automated library system, which includes acquisition, cataloguing, circulation, search modules etc. The online catalogue has 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 have also been honoured through e-mails. We had encouraged the use of the library by providing the library consultation facilities to research scholars from neighboring institutes. We had strengthened our library security with the implementation of Electro-magnetic Tattle Tapes to reduce losses.

Construction Activity

Activities related to building construction work from February-2013 was affected due to order of Hon'ble High court 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 zone. HRI has filed an application in Court for relief against this order as HRI has its own Sewage Treatment Plant (STP) with almost zero discharge and cannot cause pollution to river Ganges. The decision of Court is our case is still awaited therefore from last one year major construction activity is almost stopped.
Some miscellaneous works related maintenance/modifications were carried out during this financial year.

- Refurbishing of Nutrino cluster Room.
- Supply and fixing of Flow meter in water/sewer line.
- Modification work related to expansion in RECAPP area.
- Internal electrification in the office space of Neutrino and RECAPP projects.
- SITC of Tower AC in the office space of Neutrino and RECAPP projects.