Academic Report – 2011–12

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 has been named as a new Director of the Institute. The Institute continues to

be devoted to fundamental research in diverse areas of mathematics and theoretical physics. Research is carried out by faculty members, visiting members, post-doctoral fellows and Ph. D. students.

Since 1992 the Institute has attracted worldwide attention, as is evident from the recognition received by many of its members. Among them are Ashoke Sen, B. Mukhopadhyaya, Pinaki Majumdar, Rajesh Gopakumar are all winners of the prestigious S. S. Bhatnagar award. Ashoke Sen was also awarded the Padmashri and was elected to the Fellowship of the Royal Society. Prof. Rajesh Gopakumar had earlier won the Swarnajayanti fellowship of Department of Science and Technology and the International Centre for Theoretical Physics (ICTP) prize for 2006. Recently, Prof. Ashoke Sen was chosen for the prestigious Infosys prize in 2009.

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 computation, 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, spintronics and clusters and nanomaterials. 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. Research in quantum information and computation includes quantum algorithms, quantum communication, quantum cryptography, theory of entanglement and other nonclassical correlations, quantum dynamical maps, foundations of quantum mechanics, geometric phases, information processing in the presence of closed time-like curves, the recently developing field at the interface of quantum many-body physics and quantum information, and other related issues.

The Institute has a residential campus in Jhunsi, Allahabad with a rich 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

2011-2012 has been an eventful year for HRI. With the XI plan coming to an end in March 2012, and the XII plan to be started from April 2012 , the year has been spent trying to complete the projects of the XI plan and in making plans for the XII plan.

The most visible change on campus in the last year has been in the pace of the construction activity which is now going on full-swing. Work is being carried out for a new visitor hostel cum guest house, an extension to the library building which will house the administration besides serving as extensions to our current library and computer centre, an engineering building which will serve also as a space for stores, and a community centre extension, which will serve the residential HRI community. Although work has been started on all four fronts, in the short term, the engineering building is likely to come up first, and it has been decided to use this as a temporary hostel for the students. Work has also commenced on a block of six apartments to house post-doctoral fellows, and these apartments have also started to take shape. Plans have also started for the new conference centre and new housing which have been proposed for the next plan period.

In the last few years, the intake of students and post-doctoral fellows has increased steadily, and currently stands around sixty for students and twenty for post-doctoral fellows, with twenty two students having joined in August 2011. In the last few years, our on-campus housing has been inadequate to accommodate all of them and several apartments and rooms have been found off-campus, both in the city of Allahabad, and in Jhunsi, to house them. This trend of having off-campus housing will continue until the buildings which are now being constructed are completed.

The research activity in the institute has continued to grow and reach greater heights. It would not be out of place to mention here that the DAE report on the research output of the last five years has rated HRI at the very top among all DAE institutes in terms of quality of papers, as measured by citations per paper. Even in terms of total research output as measured in numbers of papers, HRI would be close to the top if one considers the small strength of the faculty here, i.e., if one considers the number of papers per faculty member.

HRI scientists continue to be nationally and internationally recognized for their work and this year has been no different. Prof. Ravindran has been

elected a fellow of the Indian Academy of Sciences, Bangalore.

The conferences, schools and workshops schedule of the institute has been growing so rapidly that the different groups in the institute need to book their time slots more than a year in advance, because of constraints not only on accommodation, but also on other infrastructural things like auditorium and lecture rooms and also the administrative personnel who have to cope with all the extra work. Almost every week between end-September to early March this year has been utilized for some conference or school and groups have already started booking their time slots for 2012-2013. One of the reasons for the success of our schools and conferences is that we have a peaceful location, away from the city, where students, faculty, experts all are housed together on campus. This affords enough time and possibilities for interaction even beyond the lectures and talks. This makes it a popular venue for many speakers and lecturers not only from India, but also from abroad. Many of our visitors have expressed their interest to come here again for lectures and visits.
Even in the slack summer season, this year, as in other years, we had the SPIM programme for maths students and rhe VSP programme for the physics students. These have become very popular in the last few years, and we often have to turn away good students due to accommodation and other constraints.

On the academic named lecture front, in the last year, three Triveni lectures were arranged. Prof. Vladimir Voevodsky from IAS, Princeton, gave the fifth Triveni lecture on 'Mathematics and Computers' on 16th February 2011. The sixth and seventh Triveni lectures were given by Professor M.S. Narasimhan, who spoke on What do mathematicians do and how on October 1, 2011 and Professor Charles Bennett of IBM, who spoke on Quantum information, the ambiguity of the past, and the complexity of the present on February 24, 2012. There were also a couple of HRI-Girdharilal Mehta lectures. On the 28th of March, 2011, Dr. S. Banerjee, DAE Secretary delivered the 12th HRI-Girdharilal Mehta lecture on 'Order and chaos' and on January 14, 2012, Professor Subir Sachdev of Harvard University, spoke on Quantum entanglement and the phases of matter . Prof. Michael Waldschmidt of University of Paris VI, gave a public lecture on Transcendental Numbers on December 9, 2011 and Prof. S.G. Dani of TIFR, Mumbai gave the INSA Srinivasa Ramanujan Medal Lecture on Continued fractions and applications to values of quadratic forms on September 30, 2011.

As in other years, HRI conducted Science Talent Tests in mathematics and physics for school students in the Allahabad area. Students of the 10th and 12th classes in many schools in Allahabad appeared in this test. The top-

pers were awarded prizes in a special function organized at HRI, which this year was held on January 20, 2012. A number of Science Talent Test prize winners have gone on to flourishing careers in science and engineering later on in life.

On the infrastructure side, the computing centre of the institute upgraded around 200 computers of the institute in the period between November 2011 - March 2012. The internet connectivity of the institute, which, in some sense, is the lifeline of an isolated institute like HRI needs constant upgrading, and this has been done in the last year as well. Besides, bandwidth from other service providers, the National Knowledge Network (NKN) with a 1Gbps connectivity has been made operational and has been working well since September 2011. Further, a new 50 node cluster has been recently bought and installed. Services in the library have been upgraded with new computers and a new photocopying machine.

On the administrative side, all staff members who have joined the institute on or after 1st January, 2004 have been placed under the new pension scheme and have now received PRAN KITS. The employees and employers contributions to NPS have been transferred to the NPS account. We have requested DAE for a one time grant to cover the interest and this is still awaited. The performance related incentive scheme (PRIS) payments for 2009-2010 have been made to all the eligible staff of HRI.

We have had some major changes in the staff at the institute. Prof. Raychaudhuri, our director for the last 6 years, left for Kolkata in May. Dr. J. S. Bagla has also resigned from his position as a faculty at HRI and has joined IISER at Mohali, and Dr. Tirthankar Roy Choudhury has been granted 18 months lien to join NCRA, Pune. On the other hand, Dr. Anirban Basu joined as a faculty member from IOP, Bhubaneswar, and we have made some more faculty offers which have been accepted.

On the administration side also, we have had some major changes with Mr. Ravindra Singh joining as a new registrar in December. We have also had Mr. Om Karn join as the junior hindi translator and Mr. Umesh Kumar Singh as the stores and purchase officer.

Acting Director
(*Director-in-charge*)

Sumathi Rao

List of Governing Council Members

(2011 -12)

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

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

3. Dr. J.N.De,
   BH-135, Sector-II
   Salt Lake
   KOLKATA - 700 091

4. Prof. Narendra Kumar
   Raman Research Institute
   C.V. Raman Avenue,
   Sadashivanagar
   Bangalore - 560 080

5. Shri S.L. Mehta
   4, Clive Row
   KOLKATA - 700 001

6. Shri Avnish Mehta
   4, Penn Road,
   KOLKATA- 700 027

7. Shri Rama Kant Misra,IAS (Retd.) 22 / 1E, P.C. Banerjee Road
   Allen Ganj
   ALLAHABAD - 211002

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

9. Director, Higher Education, U.P.
   Near G.P.O, Civil Lines,
   ALLAHABAD - 211 001

10. Shri V.R.Sadasivam
    Joint Secretary (F)
    Govt. of India,
    Deptt. of Atomic Energy,
    Chhatrapati Shivaji Maharaj Marg,
    MUMBAI - 400 001

11. Dr. C B S Venkatramana
    Joint Secretary (R&D),
    Govt. of India,
    Deptt. of Atomic Energy,
    Anushakti Bhavan,
    Chhatrapati Shivaji Maharaj Marg,
    MUMBAI - 400 001

12. Director, Harish-Chandra Research Institute (Ex. Officio)
    Chhatnag Road, Jhunsi
    Allahabad - 211 019

ACADEMIC STAFF

Faculty Members (Mathematics)

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

Faculty Members (Physics)

1. Prof. B. Mukhopadhyaya
2. Prof. S. Naik
3. Prof. Sudhakar Panda
4. Prof. Raj Gandhi
5. Prof. Ashoke Sen
6. Prof. Sumathi Rao
7. Prof. Dileep Jatkar
8. Prof. Pinaki Majumdar
9. Prof. V. Ravindran

10. Prof. Rajesh Gopakumar
11. Dr. T. P. Pareek
12. Dr. Prasenjit Sen
13. Dr. Tapas Kumar Das
14. Dr. Aseshkrishna Datta
15. Dr. Sandhya Choubey
16. Dr. Tirthankar Roy Choudhury
17. Dr. Ujjwal Sen
18. Dr. Aditi Sen De
19. Dr. G.Venketeswara Pai
20. Dr. Arun Kumar Pati
21. Dr. Anirban Basu

Administrative Staff

1. Shri Ravindra Singh [Registrar]
2. Shri Rajkumar Gulati [Accounts Officer]
3. Dr. Vijay Raghav Tiwari [Librarian]
4. Shri Manish Sharma [Scientific Officer 'D']
5. Shri Amit Roy [Internal-Audit-cum Administrative officer]
6. Shri Sanjai Verma [System Manager]
7. Shri Prabhat Kumar [Senior Private Secretary]
8. Shri K.S. Shukla [Professional Assistant]
9. Shri A.K. Srivastava [SO (SB) (Electrical)]
10. Shri V.K. Srivastava [SO SB (Civil)]
11. Shri Jagannath Yadav [Accountant]
12. Shri R.P. Sharma [Manager Guest House]
13. Ms. Archana Tandon [Office Superintendent]
14. Ms. Anju Verma [Scientific Assistant]
15. Shri U.K. Dwivedi [Cashier]
16. Shri D. Malhotra [Upper Division Clerk]
17. Shri K.K. Srivastava [Upper Division Clerk]
18. Shri Yashpal Singh [Stenographer]
19. Ms. Sumitra [Upper Division Clerk]
20. Ms. Seema Agarwal [Receptionist]
21. Mr. Om Kumar Karn [Junior Hindi Translator]
22. Shri Umesh Kumar Singh [Store/Purchase Officer]
23. Shri P.N. Mishra [Jr. Lib. Assistant]
24. Shri D.P. Sharma [Jr. Lib. Assistant]

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

Visiting Fellow

Mathematics

1. Dr. Saurabh Kumar Srivastava
2. Dr. Ashwin S. Pande
3. Dr. Umesh Vanktesh Dubey
4. Dr. Saikat Chatterjee
5. Dr. Anitha Thillaisundaram

Physics

1. Mr. Sanjoy Datta
2. Mr. Akhilesh
3. Dr. Pooja Srivastava
4. Dr. Sayantani Bhattacharyya
5. Dr. Efgnwande Osoba
6. Dr. Satoshi Ohya
7. Dr. Itzadah Thongkool
8. Dr. Jaehyuk Oh
9. Dr. Binata Panda
10. Dr. Masahide Manabe
11. Dr. Sourav Bhattacharya
12. Dr. Kenji Nishiwaki
13. Dr. Kouhei Hasegawa
14. Dr. Anindya Biswas
15. Dr. Manabendra Nath Bera
16. Dr. Abhinav Saket

Visiting Scientist

1. Dr. Andreas Nyffeler (Physics)
2. Prof. Satya Deo (Maths)
3. Ms. Arti Girdhar (Principal Investigator of DST)
4. Dr. Suvrat Raju (Ramanujan Fellow)
5. Dr. Prabhu R. (INSPIRE Faculty)

Research Scholar

Mathematics

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

Physics

1. Mr. Rajarshi Tiwari
2. Mr. Shailesh Lal
3. Mr. Dhiraj Kumar Hazra
4. Mr. Satyanarayan Mukhopadhyay
5. Ms. Desai Nishita D.
6. Mr. Ram Lal Awasthi
7. Mr. Manoj Kumar Mandal
8. Mr. Atri Bhattacharya
9. Mr. Saurabh Niyogi
10. Mr. Arunabha Saha
11. Mr. Ujjal Kumar Dey
12. Mr. Saurabh Pradhan
13. Mr. Vikas Chauhan
14. Mr. Sourav Mitra
15. Mr. Sabyasachi Tarat
16. Mr. Nyayabanta Swain
17. Mr. Abhishek Chowdhury
18. Mr. Swapnamay Mondal
19. Ms. Akansha Singh
20. Ms. Shrobona Bagchi
21. Mr. Raghunath Ghara
22. Mr. Dharmadas Jash
23. Mr. Mehedi Masud
24. Mr. Avijit Misra

25. Mr. Narayan Rana
26. Mr. Maguni Mahakhud
27. Ms. Avinanda Chaudhuri
28. Mr. Utkarsh Mishra
29. Ms. Ushoshi Maitra
30. Mr. Udit Narayan Chawdhury
31. Mr. Roji Pius
32. Mr. Taushif Ahmed
33. Mr. Aritra Gupta
34. Mr. Abhishek Joshi
35. Mr. Shankha Banerjee
36. Mr. Uttam Singh
37. Mr. Kadge Samrat Suresh
38. Mr. Dibya Kanti Mukherjee
39. Mr. Arijit Dutta
40. Mr. Soumyadeep Chaudhuri
41. Mr. Sauri Bhattacharya
42. Mr. Saikat Banerjee
43. Mr.Tamoghna Das
44. Mr. Krashna Mohan Tripathi
45. Mr. Asutosh Kumar
46. Mr. Debasis Mondal
47. Mr. Ashis Kumar Pal
48. Mr. Nabarun Chakrabarty
49. Mr. Aditya Banerjee

50. Mr. Udit Khanna
51. Mr. Ali Sarosh Ansar
52. Mr. Alok Kumar Sinha
53. Ms. Ajanta Maity

Academic Report - Mathematics

Sukumar Das Adhikari

Research Summary:

Publications:

1. Sukumar Das Adhikari and Mohan N. Chintamani, *Number of weighted subsequence sums with weights in* $\{1, -1\}$, Integers **11**, paper A 36, (2011).

2. Sukumar Das Adhikari, David J. Grynkiewicz, and Zhi-Wei Sun, *On Weighted Zero-sum Sequences,* Advances in Applied Mathematics **48**, 506-527, (2012).

Preprints:

1. Sukumar Das Adhikari and Purusottam Rath, *Remarks on monochromatic configurations for finite colorings of the plane,* Note di Matematica, To appear.

2. Sukumar Das Adhikari, Eshita Mazumdar and Sneh Bala Sinha, *Erdős, Ginzburg and Ziv Theorem: various proofs and some generalizations,* Proceedings of the 21st Annual Conference of the Jammu Mathematical Society, To appear.

Conference/Workshops Attended:

1. *Symposium in Number Theory at Bhaskaracharya Pratishthana, Pune, jointly organised by IISER, Pune and BP, Pune,* India, 31st May - 3rd June, 2011.

2. *27th Journées Arithmétiques*, Vilnius university, Lithuania, 27th June - 1st July, 2011.

3. *Mathematics Education - Trends and Challenges*, at Univ. of Hyderabad, India, August 19-21, 2011.

4. *Instructional Workshop on Additive Combinatorics*, HRI, Allahabad, India, 26th Sept. to 1st Oct. 2011.

5. *26th Annual Conference of Ramanujan Mathematical Society*, Allahabad, India, October 2-5, 2011.

6. *International Conference on Number Theory*, HRI, Allahabad, India, December 15-20, 2011.

Visits to other Institutes:

1. Ramakrishna Mission Vivekananda University, Belur, India, April 2011 and March 2012.
2. School of Mathematics, TIFR, Mumbai, India, April 2011.
3. Departament de Matemàtica Aplicada IV, Barcelona, Spain, April 25-30, 2011.
4. Mathematics Department, Niigata University, Japan, May 7 - 15, 2011.
5. Bhaskaracharya Pratishthana, Pune, India, June, 2011.
6. Laboratoire de Mathématiques Pure et Appliquées, Université du Littoral, Calais, France, June 16-17, 2011.
7. Univ Paris VI, France, June 18 - 21, 2011.
8. Vilnius University, Lithuania, June 22-July 2, 2011.
9. University of Rome III, Italy, July 3 - 6, 2011.
10. IISER, Kolkata, India, August, 2011.
11. The Institute of Mathematical Sciences (IMSc), Chennai, India, January 24 - February 11, 2012.

Invited Lectures/Seminars:

1. *Two classical results in Additive Combinatorics: Some related recent results*, Mathematics Colloquium, School of Mathematics, TIFR, Mumbai, 7th April, 2011.
2. *Integer lattice points in the plane*, Seminari Combinatòria, Teoria de Grafs i Applicacions, Departament de Matemàtica Aplicada IV, Barcelona, Spain, 28th April, 2011.
3. *Introduction to zero-sum problems* (two talks), *Two problems related to integer lattice points in the plane* (Colloquium), Symposium in Number Theory, Bhaskaracharya Pratishthana, Pune, 31st May - 3rd June, 2011.
4. *Two problems related to integer lattice points in the plane*, Invited talk, Laboratoire de Mathématiques Pure et Appliquées, Université du Littoral, Calais, France, 17th June, 2011.

5. *Weighted zero-sum problems*, Conference talk, 27th Journées Arithmétiques, Vilnius University, Lithuania, June 22-July 2, 2011.

6. *Weighted sums in Finite abelian groups*, Invited talk, IISER, Kolkata, India, 17th August, 2011.

7. *Early Ramsey-type Theorems in Combinatorial Number Theory*, Invited talk, Annual Mathematics Festival, Analytica 2011, at St. Xavier's College, Kolkata, 22nd September, 2011.

8. *Some zero-sum problems in Combinatorial Number Theory*, Invited talk, Department of Mathematics, Presidency University (Formerly Presidency College) Kolkata, 22nd September, 2011.

9. *Course of lectures in Instructional Workshop on Additive Combinatorics*, HRI, Allahabad, 26th Sept to 1st October, 2011.

10. *On some Ramsey-type theorems on the integers*, Invited talk, Symposium on Ramanujan's Life, Work and Interests, NIIT University Neemrana, Rajasthan, 25-26 November, 2011.

11. *Quadratic Reciprocity and related results*, A course of lectures in the ATML workshop on Number Theory held during 22nd December, 2011 to 4th January, 2012 at HRI, Allahabad.

Academic recognition/Awards:

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

Other Activities:

1. Currently suprvising two Ph. D. students.

2. Served on the following committees of the institute: Foreign Travel Committee, HBNI Cell, DAE Liaison regarding Academic and Plan issues, Appointment of Faculty, Budget Review and Planning, Faculty Advisory Committee, Grievance.

3. Had been Dean (academic), Harish-Chandra Research Institute till December 2011.

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

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

6. Gave a couple of lectures to the M. Sc. students at Ramakrishna Mission Vivekananda University, Belur, in April 2011.

7. Participated and was a member of a Panel at the meeting 'Mathematics Education - Trends and Challenges' held at Univ. of Hyderabad during August 19-21.

8. Was a member of the Local Organizing Committee of the 26th Annual Conference of Ramanujan Mathematical Society held during October 2-5, 2011, at the Department of Mathematics, University of Allahabad.

9. Gave a course of lectures on 'Sequences and Transcendence' for the second year Ph. D. students at HRI during August - December 2011.

10. Was one of the organisers of the 'International Conference on Number Theory', held at HRI, Allahabad, during December 15-20, 2011.

11. Gave some lectures on 'Modules over commutative rings' for the first year M. Sc. students at Ramakrishna Mission Vivekananda University, Belur, in March 2012.

Punita Batra

Research Summary:

In a joint work with H. Yamane, we found out the center of rank-one quantum groups. We also obtained the center of generalized quantum group (GQG). We used Lusztig isomorphism in rank-one cases.

Preprints:

1. Punita Batra, Hiroyuki Yamane, *Center of Generalized Quantum Group* (in preparation).

Conference/Workshops Attended:

1. *International Conference on Infinite Dimensional Lie Theory and its Applications,* Tehran, Iran, May 14-17, 2011.
2. *Representation Theory XII,* conference at Inter-University Centre, Dubrovnik, Croatia, June 19-24, 2011.
3. *26th Annual Conference of Ramanujan Mathematical Society,* University of Allahabad, Allahabad, October 2-5, 2011.
4. *Indian Women and Mathematics,* conference at IMSc, Chennai, January 8-10, 2012.

Visits to other Institutes:

1. IPM, School of Mathematics, Tehran, Iran, May 14-20, 2011.
2. Inter-University Centre, Dubrovnik, Croatia, June 19-24, 2011.
3. Chennai Mathematical Institute, Chennai, July 12-15, 2011.
4. IMSc, Chennai, January 8-10, 2012.

Invited Lectures/Seminars:

1. *Twisted Toroidal Lie Algebras and their modules*, International Conference on Infinite Dimensional Lie Theory and its Applications, IPM, Tehran, May 16, 2011.

2. *Highest weight modules over pre-exp-polynomial Lie algebras*, International Conference on Representation Theory XII, Inter-University Centre, Dubrovnik, June 22, 2011.

3. Gave four lectures on *Kac-Moody Lie algebras*, Advanced Instructional School on Lie Algebras, CMI, Chennai, July 12-15, 2011.

4. *Highest weight modules over pre-exp-polynomial Lie algebras* in the Lie Groups session of 26th Annual Conference of Ramanujan Mathematical Society, University of Allahabad, October 4, 2011.

5. "Group Leader" talk on *Lie algebras* followed by group discussion at the conference Indian Women and Mathematics, IMSc, Chennai, January 8, 2012.

Other Activities:

1. Gave two lectures in the Rajbhasha scientific workshop at HRI in May 2011.

2. Gave five lectures on "Field Extensions and Galois Theory" in Summer Programme in Mathematics(SPIM) at HRI in June, 2011.

3. Taught a first year graduate course Algebra-I at HRI during August-December 15, 2011.

4. Organised an ATM workshop "Lie Groups and Lie Algebras" at HRI during August 22-27, 2011. Also delivered four lectures in this workshop.

5. Organised an International conference "Group Theory and Lie Theory" at HRI during March 19-21, 2012.

6. Advised one winter student from IISER Mohali on Lie algebra project for one month during December 2011.

7. Member of the Mathematics Visitor's Committee of HRI. Also serving as a member in the Rajbhasha Committee, the Sports and Entertainment Committee and the SYM(Special Years in Mathematics) Committee.

Kalyan Chakraborty

Research Summary:

In a joint work with Jay Mehta, we proposed a stamped blind signature scheme based on elliptic curve discrete log problem and hash functions. We also studied couple of well-known key exchange cryptographic protocols. We suggested an alternative way to prevent the 'unknown-key share attack' on these protocols using cryptographic biliear maps by adding a third pass. I am also studying arithmetical functions functions satisfying some interesting relations. This study is being done jointly with Jay Mehta, Imre Katai and Bui Minh Phong. In a joint work with Makoto Minamide, we have studied L-functions associated to Maass forms and work is in progress for further study. I am also continuing my study of various kinds of special functions jointly with S. Kanemitsu and others. Work is also in progress jointly with Y. Kishi to study the divisibility of class number of quadratic fields.

Publications:

1. Kalyan Chakraborty and Jay Mehta, *A Stamped Blind Signature Scheme based on Elliptic curve Discrete Log Problem*, Appear in International Journal of Network Security.

2. Kalyan Chakraborty and Jay Mehta, *On completely multiplicative complex valued funtions*, Annales Univ. Sci. Budapest, Sect. Comp. No. 38 (2012).

3. K Chakraborty, S. Kanemitsu and H. Tsukada, *Arithmetical Fourier series and the modular relation*, Kyushu J. Math., Vol.66, No.2, (2012).

4. Kalyan chakraborty, Imre Katai and Bui Minh Phong, *On real valued additive functions modulo 1*, Annales Univ. Sci. Budapest, Sect. Comp. No. 36 (2012), 355–373.

5. K. Chakraborty, S. Kanemitsu and X.-H. Wang, *The modular relation and the digamma function*, Kyushu J. Math., 65, (2011), 39–53.

Preprints:

1. Kalyan Chakraborty and Jay Mehta, *Preventing Unknown Key Share attack using Cryptographic Bilinear Maps*, HRI-M-12-04-003.
2. K. Chakraborty, S. Kanemitsu and T. Kuzumaki, *Multiple zeta function*, HRI-M-12-05-004.
3. Kalyan chakraborty, Jorge Jime'nez Urroz and Francesco Pappalardi, *Pairs of integers which are mutually squares*, HRI-M-12-05-009.
4. Kalyan Chakraborty and Makoto Minamide, *On partial sums of a special analogue of the Mobius function*, HRI-M-12-05-005.
5. Kalyan Chakraborty, I. Katai and B. M. Pong, *On additive functions satisfying some relations*, HRI-M-12-05-008.
6. Kalyan Chakraborty, Imre Katai and Bui Minh Phong, *On the values of arithmetic functions in short intervals* (In preparation).
7. Kalyan Chakraborty, Imre Katai and Bui Minh Phong, *On additive functions with values in an abelian group* (In preparation)

Conference/Workshops Attended:

1. International Conference in Number Theory, HRI, December, 2011.

Visits to other Institutes:

1. Tribhuvan University, Nepal, November, 2011.
2. Lorant Eotvos University, Budapest (Hungary), May, 2011.

Invited Lectures/Seminars:

1. Lectures on Introduction to Theory of Numbers, Nepal, November,2011 (under the guidence of CIMPA).
2. Introduction to Cryptography, Inspire Programme, 18th april, Allahabad.

Other Activities:

1. Conduct(as Zonal Co-ordinator) NBHM Tests and Interviews to award M.Sc./Ph.D fellowships.
2. Reviewer of AMS.
3. Refereed a Ph.D thesis from Burdwan University.

Chandan Singh Dalawat

Research Summary:

For any finite extension F of $\mathbf{Q}_p$ or of $\mathbf{F}_p(\!(t)\!)$, there is a natural map from the set $\mathcal{S}_p(F)$ of separable degree-p extensions of F into the group $F^\times/F^{\times p-1}$. We have computed the contribution to Serre's mass formula coming from all $E \in \mathcal{S}_p(F)$ mapping to a given $\chi \in F^\times/F^{\times p-1}$. It turns out that the contribution of *peu ramifiées* extensions depends only on the "valuation" $\bar{v}(\chi) \in \mathbf{Z}/(p-1)\mathbf{Z}$ of χ. Summing over all χ gives back Serre's mass formula in degree p.

As a corollary, one gets an explicit formula for the contribution of cyclic extensions, or those extensions which become cyclic over an *unramified* extension of F, for example. Given a finite group Γ (extension of a cyclic group of order dividing $p-1$ by a group of order p), one can compute the contribution of those E whose galoisian closure $\tilde{E}|F$ has group Γ. Also, given a finite extension $F'|F$ (cyclic of degree dividing $p-1$), one can compute the contribution of those E for which $\tilde{E} = EF'$.

Preprints:

1. Chandan Singh Dalawat, *§9 of Serre's "formule de masse" in prime degree*, 6 pp., `arXiv:1005.2016v6`.
2. Chandan Singh Dalawat, *Quelques "formules de masse" raffiées en degré premier*, 7 pp., `arXiv:1110.6702v1`.

Conferences/Workshops Attended:

1. *Thérie de Hodge p-adique, équations différentielles p-adiques, et leurs applications*, Lyon, 6–10 June 2011.
2. *Annual Meeting of the Ramanujan Mathematical Society*, Allahabad, 2–5 October 2011.

Visits to other Institutes:

1. Université de Rennes 1, Rennes, 25 May–19 June, 2011.
2. Université de Paris 13, Villetaneuse, 20–24 June, 2011.
3. Tata Instiute of Fundamental Research, Bombay, 7–18 November, 2011.

Invited Lectures/Seminars:

1. *The ramification filtration*, Yonsei University, 2 May 2011; Korea Institute for Advanced Study, 11 May 2011.
2. *Serre's mass formula in prime degree*, Korea Institute for Advanced Study, 12 May 2011, Tata Institute of Fundamental Research, 19 May 2011.
3. *Higher Reciprocity Laws*, Tata Institute of Fundamental Research, 19 May 2011.
4. *La formule de masse de Serre en degré premier*, Université de Rennes 1, 16 May 2011; Université de Paris 13, 24 June 2011.
5. *Galois's Last Theorem*, Annual meeting of the Ramanujan Mathematical Society, Allahabad, 5 October 2011.
6. *Two lectures on constructibiltiy and solvability*, Birla Institute of Technology and Science, Goa, 11 and 12 November 2011.
7. *Some refinements of Serre's mass formula in prime degree*, Students' Seminar, Tata Instiute of Fundamental Research, Bombay, 18 November 2011.
8. *Two interactive sessions at the Science conclave*, Indian Institute of Information Technology, Allahabad, 28–29 November, 2011.
9. *Five lectures on the Hilbert symbol*, Advanced Training in Mathematics school for lecturers, Number Theory, Allahabad, 26–30 December, 2011.
10. *Artin's general reciprocity law*, Advanced Training in Mathematics school for lecturers, Number Theory, Allahabad, 5 January, 2012.

Other Activities:

Supervised an undergraduate student from BITS Goa. Resource person during the Nobel Laureates' Conclave at IIIT Allahabad.

Rukmini Dey

Research Summary:

I had previously carried out geometric quantization of the vortex moduli space using the holomorphic Quillen determinant bundle. This holomorphic quantization of the vortex moduli space (via Quillen bundle) and the vortices on a sphere led to a paper, jointly with Professor Mathai Varghese. This basically says that given an integral Kähler form on a compact Kähler manifold, some tensor product of the corresponding line bundle is a Quillen determinant bundle. This is very significant and confirms (to a certain extent) the view point of the two authors that the Quillen bundle (with suitable modifications) is universal in geometric quantization. We are currently studying the semi-classical limit of the theory, using the Berezin transform.
The holomorphic quantization of the vortex moduli space (via the Quillen bundle) is also interesting and might lead to finding explicitly the Hilbert space of the quantizaion for genus $g > 0$, which has not been found yet. This involves embedding the vortex moduli space, with its usual Kähler metric into CP^N using the Kodaira embedding theorem.
Another work which was completed is the interpolation of two real analytic curves by piecewise minimal surfaces. A description of the idea is as follows: given two wire frames, one can insert a series of wire frames such that there is a series of minimal surfaces interpolating between frame to frame. This we prove using the solution to the Bjorling problem and the inverse function theorem.
With Pradip Kumar Mishra, my student, I have related Born-Infeld solitons to minimal surfaces which led to a paper.
With two other physicists I am working on geometric prequantization of the Hamiltonians in finite Toda systems.

Publications:

1. Rukmini Dey and Pradip Kumar, *One parameter family of solitons from minimal surfaces,* accepted in Proceedings of Indian Academy of Sciences; arxiv:1204.5875

2. S. Agarwal, T.K. Das, R. Dey and S. Nag , *An Analytical Study on the Multi-critical Behaviour and Related Bifurcation Phenomena for Relativistic Black Hole Accretion ,* accepted in General Relativity and Gravity

Preprints:

1. Rukmini Dey, Varghese Mathai, *Holomorphic Quillen bundle over compact Kähler manifolds* arXiv:1202.5213
2. *Geometric Quantization of the vortex moduli space with its usual symplectic form: a review*
3. Rukmini Dey, *Geometric prequantization of various moduli spaces: a review* (in preparation)
4. Rukmini Dey, *Piecewise minimal surfaces interpolating between two real analytic curves* arXiv: 1204.5833

Conference/Workshops Attended:

1. *National Conference on Recent Advances in Mathematics*, India, Feb, 2012.
2. *Indian Women and Mathematics*, India, Jan, 2012.

Visits to other Institutes:

1. S.N. Bose Center, Kolkata, India, May 2011.

Invited Lectures/Seminars:

1. *Some Aspects of Minimal Surfaces* , National Conference on Recent Advances in Mathematics, Lucknow University, Lucknow, Feb, 2012.
2. *Minimal surfaces*, Indian Women and Mathematics, I.M.Sc, Chennai, Jan, 2012.

Academic recognition/Awards:

- Adjunct Faculty, I.C.T.S., Bangalore, 2011-2013.
- Editorial Board, International Journal of Physics and Mathematical Sciences, Centre for Info Bio Technology (CIBTech), 2012.

Other Activities:

1. Currently Ph.D guide to a graduate student, Mr. Pradip Kumar.
2. Project Coordinator to a graduate student, Mr. Rahul Kumar Singh, Differential Geometry of Curves and Surfaces, HRI, Aug, 2011- May 2012.
3. Instructor, Topology II, HRI, January-May, 2012.
4. Instructor, Topology I, HRI, August-December, 2011.
5. Co-organizer, Discussion meet on Analysis and Geometry II, March 12-16, 2012.
6. As a member of the Mathematics seminar and HRI colloqiuim committees I have organized various mathematics seminars and some HRI colloquia.

D. Surya Ramana

Research Summary:

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

In joint work in progress with J. Cilleruelo and O. Ramaré, we generalise a method described in an earlier work by us for obtaining lower bound for ratios of integers from a subset of an interval, specified only by its cardinality. Our purpose is to cover sets such as the shifted primes.

Preprints:

1. P. Akhilesh and D.S. Ramana, *A Remark on the Buerling Selberg Function,* submitted.

2. D.S. Ramana and O. Ramaré, *Additive Energy of Dense Sets of Primes and Monochromatic Representation,* submitted.

Visits to other Institutes:

1. University of Lille, Lille, France, May and then again from September to November 2011.

2. Universidad Autonoma de Madrid, Madrid, Spain, November 2011.

3. Alfred Renyi Institute, Hungarian Academy of Sciences, Budapest, November, 2011.

Invited Lectures/Seminars:

1. *Additive Energy of Dense sets of Primes and Monochromatic Representation*, Arithmetique en plat pays, Catholic University Leuven, Leuven, September 2011.

2. A course of ten hours on Probabilistic Galois Theory, University of Lille, Lille, September to November 2011.

Other Activities:

1. Organised (with Dr. R. Thangadurai) the ATM school for Lecturers in Number Theory in December 2011 at HRI, Allahabad.

2. Gave a short course of three lectures at Kumaon University, Almora on the Chevalley-Warning Theorem in March 2012.

3. Served on the organising committee for the International Conference on Number Theory, HRI, December 2011.

4. Served on the Local Works Committee of the institute as well as the Graduate Committee in Mathematics, as convenor, from January, 2012.

Ramakrishnan B

Research Summary:

1. Restriction map for Jacobi forms (joint work with Karam Deo Shankhadhar): Let D_0 be the restriction map from the space of Jacobi forms of weight k, index m on the congruence subgroup $\Gamma_0(N)$ to that of elliptic modular forms of the same weight on $\Gamma_0(N)$, given by $\phi(\tau, z) \mapsto \phi(\tau, 0)$. More generally, one obtains modular forms of weight $k+\nu$ by using certain differential operators D_ν. Then it is known that $\oplus_{\nu=0}^{m} D_{2\nu}$ is injective for k even, but when $k \geq 4$, it is well-known that the map D_0 is far from being injective. However, J. Kramer and T. Arakawa & S. Böcherer observed that when $k = 2$ the situation may be different. In fact, when $m = 1$, Arakawa and Böcherer provided two explicit descriptions of $\mathrm{Ker}(D_0)$: one in terms of modular forms of weight $k-1$ and the other in terms of modular forms of weight $k+2$ (by applying the differential operator D_2 on $\mathrm{Ker}(D_0)$). In a subsequent paper, they proved that D_0 is injective in the case $k = 2, m = 1$ and gave some applications. In a private communication to the authors, Professor Böcherer informed that one of his students gave a precise description of the image of $D_0 \oplus D_2$ in terms of vanishing orders in the cusps (k arbitrary, $m = 1$). Based on this,he conjectured that in the case $k = 2$, one can remove one of the $D_{2\nu}$ from the direct sum $\oplus_{\nu=0}^{m} D_{2\nu}$.
In this work, we generalize the results of Arakawa-Böcherer to higher index. First, we consider the case $m = 2$ and show that $\mathrm{Ker}(D_0)$ is isomorphic to the space of vector-valued modular forms of weight $k-1$ and $D_2(\mathrm{Ker}(D_0))$ is isomorphic to a certain subspace of cusp forms of weight $k+2$ and these two spaces are related with each other by a simple isomorphism. Next, we obtain the injectivity of $D_0 \oplus D_2$ on $J_{2,2}(\Gamma_0(2N))$, where $N = 2$ or an odd square-free positive integer. This confirms the conjecture made by Professor Böcherer partially in the index 2 case (i.e., we can omit the operator D_4). Finally, we consider a subspace of $J_{k,m}(\Gamma_0(mN), \chi)$, where m is a square-free positive integer and N is any positive integer and obtain results similar to Arakawa-Böcherer and prove the injectivity of D_0 on this subspace when $k = 2$, mN square-free. At the end we make several remarks concerning the subspace studied in our work.

2. Non-vanishing of L-functions of half-integral weight (Revised version) (joint work with Karam Deo Shankhadhar): In 1997, W. Kohnen showed that a certain average of L-functions over a basis of cusp forms of integral weight on $\mathrm{SL}_2(\mathbf{Z})$ does not vanish in large parts of the critical strip. As a consequence, he proved that for any point s inside the critical strip not lying on the line $\mathrm{Re}(s) = k/2$, there exists a Hecke eigen cusp form of in-

tegral weight k on $SL_2(\mathbf{Z})$, such that the corresponding L-function value at s is non-zero for sufficiently large k. In 2005, A. Raghuram generalised Kohnen's method for the average of L-functions over a basis of newforms (of integral weight) of level N with primitive character modulo N. In this article, we extend Kohnen's method to forms of half-integral weight. As a consequence, we show that for any given point s inside the critical strip not lying on the line $\mathrm{Re}(s) = k/2+1/4$, there exists a Hecke eigen cusp form f of half-integral weight $k + 1/2$ on $\Gamma_0(4N)$ with character ψ such that the corresponding L-function value at s is non-zero, and the first Fourier coefficient of f is non-zero. Our results are obtained for N sufficiently large if k is fixed and vice versa. In particular when $N = 1$, for sufficiently large k, either f is a newform in the full space or f is a Hecke eigenform in the Kohnen plus space. It should be noted that the normalisation of Fourier coefficients of forms of half-integral weight is still an open question.

3. Theory of newforms of half-integral weight (joint work with M. Manickam and Jaban Meher): Let $M = 2^a N$, N is an odd square-free positive integer, a is an integer, $0 \leq a \leq 2$. Let χ be a real Dirichlet character modulo M and χ is primitive modulo 8 if $a = 2$. By explicit computation of traces M. Ueda proved that there exists a Hecke equivariant isomorphism between the spaces $S_{k+1/2}(4M, \chi)$ and $S_{2k}(2M)$. In this work, we set up the theory of newforms for both the Kohnen plus space and the full space on these spaces $S_{k+1/2}(2^{a+2}N, \chi)$, for $0 \leq a \leq 2$ and χ is primitive modulo 8 if $a = 2$. The theory of newforms is known for the spaces when $a = 0$ by the work of W. Kohnen and Manickam-Ramakrishnan-Vasudevan. If $a = 1$ the theory is known for the full space by the work of Manickam and for the Kohnen plus space by a recent result of M. Ueda and S. Yamana. Using the Ueda's isomorphism as a main tool, we establish the theory of newforms for the remaining cases for both the Kohnen plus space and the full space. Using the explicit dimension formulas, we observe that the Shimura maps $\mathcal{S}_{t,16N}$ maps the space $S_{k+1/2}(16N)$ into $S_{2k}(4N)$ and thereby we deduce that there is no newform space on $S_{k+1/2}(16N)$. However, we establish the theory of newforms for $S_{k+1/2}(16N, \chi)$, which is compatible with integral weight theory when χ is a primitive character modulo 8.

4. Correspondence between higher degree Jacobi forms and modular forms of integral weight (joint work with Karam Deo Shankhadhar): In [Invent. Math. **94** (1988)], N. -P. Skoruppa and D. Zagier constructed certain lifting maps (Shimura type correspondence) between the space of Jacobi cusp forms of integral weight and a subspace of cusp forms of integral weight. Further, in [Math. Ann. **278**(1987)], B. Gross, W. Kohnen and D. Zagier constructed a kernel function for these liftings. By using these cor-

respondences, they obtained deep formulas relating to the height pairings of Heegner points to the Fourier coefficients of Jacobi forms. This correspondence for the general level (for subgroups of the full Jacobi group) was generalized by B. Ramakrishnan in his thesis. In [Trans. Amer. Math. Soc. **352** (2000)], the same results were obtained by M. Manickam and B. Ramakrishnan by showing that the image of the Poincaré series under the Shimura map can be expressed in terms of the holomorphic kernels of the periods of cusp forms. In [Math. Z. **253** (2006)], K. Bringmann generalized these liftings to Jacobi forms of higher degree (in particular to Jacobi forms on $\mathcal{H} \times \mathbf{C}^g$ with matrix index of size g) on the full Jacobi group. In this work, we generalize the results of K. Bringmann for Jacobi forms of integral weight and matrix index for the congruence subgroups of the full Jacobi group by adopting the techniques of [Trans. Amer. Math. Soc. **352** (2000)]. By using the earlier correspondences together with our work, we obtain a correspondence between Jacobi forms of higher degree (matrix index) and Jacobi forms of degree 1 (integer index). Further work is in progress.

Publications:

1. B. Ramakrishnan, *A note on special values of certain Dirichlet L-functions*, Bull. Aust. Math. Soc. **83**, 435–438, (2011)

2. Sanoli Gun and B. Ramakrishnan, *The theta operator and the divisors of modular forms,* 'Number Theory', Ramanujan Math. Soc. Lect. Notes. Ser.,**15**, 17–30, (2011)

3. M. Manickam and B. Ramakrishnan (Eds.), *Number Theory,* Ramanujan Mathematical Society Lecture Notes Series, Number **15**, (Proceedings in Honour of Prof. T.C. Vasudevan on his Sixtieth Birthday), Ramanujan Mathematical Society, India 2011.

Preprints:

1. B. Ramakrishnan and Karam Deo Shankhadhar, *On the restriction map for Jacobi forms,* Submitted for Publication.

2. B. Ramakrishnan and Karam Deo Shankhadhar, *Non-vanishing of L-functions associated to cusp forms of half-integral weight inside the critical strip,* (Revised version), Submitted for publication.

3. M. Manickam, Jaban Meher and B. Ramakrishnan, *Newforms of half-integral weight on* $\Gamma_0(8N)$ *and* $\Gamma_0(16N)$.

4. B. Ramakrishnan and Karam Deo Shankhadhar, *On a correspondence between Jacobi cusp forms and elliptic cusp forms*, Preliminary version.

Conference/Workshops Attended:

1. *Explicit theory of automorphic forms, applications and computations, CIRM, Luminy,* France, May 2011.

2. *77th Annual Conference of the Indian Mathematical Society*, Nanded, India, December 2011.

3. *International Colloquium on Automorphic representations and L-functions*, TIFR, India, January 2012.

4. *International Workshop on Mathematics in Oman 2012*, GUtech, Oman, February 2012

Visits to other Institutes:

1. The Abdus Salam ICTP, Trieste, Italy, May/June 2011 (two weeks).

2. University of Siegen, Siegen, Germany, June 2011 (one week).

3. RWTH, Aachen, Germany, June 2011 (one week).

4. IMSc, Chennai, October 2011 & January 2012.

Invited Lectures/Seminars:

1. *Restriction map for Jacobi forms*, Explicit theory of automorphic forms, applications and computations, CIRM, Luminy, France, May 2011.

2. *Relations among Fourier coefficients of certain modular forms*, Symposium on Combinatorial Number Theory, Ramanujan Mathematical Society Annual Conference, Allahabad, October 2011.

3. *Modular forms of half-integral weight*, Ramanujan Memorial Award Lecture, IMS Annual Conference, Nanded, December 2011.

4. *The Legacy of Srinivasa Ramanujan*, *State level inauguration of National Mathematical Year 2012*, Kerala State Council for Science, Technology and Environment, Govt. of Kerala, Thiruvananthapuram, January 2012.

5. *Restriction map for Jacobi forms*, *International Workshop on Mathematics in Oman 2012*, Gutech, Oman, February 2012.

Other Activities:

1. Supervising the thesis works of two students at HRI. One of the students will be submitting his thesis in April 2012.

2. Coordinator of the Talent Search Examination (Mathematics) for school children conducted by HRI during November 2011.

3. Delivered a lecture on Ramanujan at NIIT, Neemrana, Alwar, November 2011.

4. One of the organisers of the International Meeting on Number Theory held at HRI during December 2011.

Raghavendra Nyshadham

Research Summary:

In the last one year, two students have completed their theses under my guidance. I worked with both of them in the general areas of vector bundles, and real algebraic geometry.

I have been working with a postdoctoral fellow of the Institute on a construction of moduli spaces of sheaves by Alvarez-Consul and King, which is based upon the theory of modules over Kronecker algebras.

Conference/Workshops Attended:

1. *CMI-IMSc Mathematics Colloquium*, Chennai, 23–27 January, 2012.

Invited Lectures/Seminars:

1. *Lectures on field theory*, and coorganiser, Instructional School for Lecturers on Algebra, Kumaun University, Almora, 20 February to 3 March 2012.

2. *Lectures on complex analysis*, Annual Foundational School II, Panjab University, Chandigarh, June, 2012.

Peetta Kandy Ratnakumar

Research Summary:

In the last one year I have worked mainly on two problems. The first one concerns with the well posedness result for the twisted Laplacian on $\mathbb{C}^n$. This is my main area of current research. In a joint work with Vijay Sohani we have established the existence, uniqueness and stability, for the non linear Schrödinger equation for the twisted Laplacian on $\mathbb{C}^n$. The result is valid for a large class of nonlinearity that includes power type nonlinearity. The result in complex dimension 1 can be interpreted as a result for the magnetic Schrödinger equation in the plane for the constant magnetic field. This work is submitted for publication.

The other result is a joint work with Dr. Saurabh Shrivastava on Littlewood Paley square functions. Recall that the bilinear multiplier operator associated to a smooth symbol ϕ on $\mathbb{R}^n$ is defined by

$$T_\phi(f,g)(x) = \int_{\mathbb{R}^n}\int_{\mathbb{R}^n} \hat{f}(\xi)\hat{g}(\eta)\varphi(\xi-\eta)e^{2\pi i x\cdot(\xi+\eta)}d\xi d\eta.$$

If $\{\phi_l\}$ is a family of symbols supported on cubes $Q_l \in \mathbb{R}^n$, we can consider the associated Littlewood-Paley square function given by

$$T(f,g)(x) = \sum_{\in\mathbb{Z}^n} |T_{\varphi_l}(f,g)(x)|^2)^{\frac{1}{2}}$$

We give a simple proof for the boundedness of the bilinear square function from $L^{p_1}\times L^{p_2}\to L^{p_3}$. Our result is optimal for the triplets p_1,p_2,p_3 satisfying $\frac{1}{p_1}+\frac{1}{p_2}=\frac{1}{p_3}$ i.e., $2\le p_1,p_2\le\infty, 1\le p_3\le\infty$. The result established is for multipliers ϕ_l of the form $\phi_l(x)=\phi(x-l)$ for a smooth function ϕ. This work is to appear in the proceedings of the American Mathematical Society.

Publications:

1. Ratnakumar P.K. and Saurabh Shrivastava, *On Bilinear Littlewood-Paley Square functions,* Proceedings of AMS (To appear) (2012)

Preprints:

1. Ratnakumar P.K and Vijay Kumar Sohani, *Non linear Schrodinger equation for the twisted Laplacian,* eprint number: arXiv:1204.1843v1

Conference/Workshops Attended:

1. *Recent Developments in Harmonic Analysis and their Applications*, Morocco, April 2011,
2. *Geometric and Harmonic Analysis on Homogeneous Spaces and Applications*, Tunisia, December 2011,
3. *School and Workshop on co-compact embeddings,profile decompositions and their applications to PDE*, TIFR-CAM Bangalore,January 2012.

Visits to other Institutes:

1. TIFR Centre for Applicable Mathematics, Bangalore, India, December 2011.

Invited Lectures/Seminars:

1. *A Benedick's type uncertainty principle on the Heisenberg group*, Recent Developments in Harmonic Analysis and their Applications, University of Nancy, France, held at Marrakech, Morocco, April 2011.
2. *Non-Linear Schrödinger Equation And the Twisted Laplacian*, Geometric and Harmonic Analysis on Homogeneous Spaces and Applications, Univ. of Sousse, Tunisia, December 2011.

Other Activities:

1. Taught the course, Analysis II for second year Ph. D. Students, February - May, 2012.
2. Organised the discussion meeting on Analysis and Geometry at HRI, jointly with Rukmini Dey, during 12-16th March 2012.
3. Served in the Auditorium committee and as convener for the Pantry and Guest House committee from July 2011 onwards.

Ravindranathan Thangadurai

Research Summary:

Under the special years in Number Theory at the Institute of Mathematical Sciences, Chennai, various aspects of Number Theory topics were learned. During this academic year, some diophantine problems were tackled using Siegel's Theorem; also the image of Liouville numbers under rational functions in many variables over $\mathbf{Q}$ was proved to be Liouville numbers. In order to prove such results, we defined an equivalence relation among Liouviile numbers and proving certain algebraic property of the equivalence classes. Also, distribution of residues modulo p was also studied.

Publications:

1. R. Thangadurai and A. Vatwani, *The least prime p congruent to 1 modulo n*, Amer. Math. Monthly **118**, 737-742, (2011)

2. M. N. Chintamani, W. D. Gao, B. K. Moriya, P. Paul and R. Thangadurai, *On Davenport's Constant,* Arch. Math **98**, 133-142, (2012)

3. M. Ram Murty and R. Thangadurai, *On a paper of S. S. Pillai,* Proc. Indian Acad. Sci. (Math. Sci.), **122**, 1-13, (2012)

Preprints:

1. J. Tanti and R. Thangadurai, *Distribution of residues and primitive roots* (in preparation).

2. S. Subburam and R. Thangadurai, *On norm form of Diophantine equations* (in preparation).

3. K. Senthil Kumar, R. Thangadurai and M. Waldschmidt, *On Liouville numbers* (in preparation).

4. M. Ram Murty and R. Thangadurai, *On some Diophantine equations* (in preparation).

Conference/Workshops Attended:

1. *Outreach programme for Chennai College Lecturers*, India, May, 2011.

2. *Ramanujan Mathematical Society workshop on Additive Combinatorics*, India, September, 2011.

3. *Ramanujan Mathematical Society Annual Conference*, India, October, 2011.

4. *International Meeting on Number Theory*, India, December, 2011.

5. *ATML school on Number Theory*, India, January, 2012.

6. *Workshop on Number Theory and Cryptography*, India, February, 2012.

7. *ATML school on Galois Theory*, India, March, 2012.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, April-May, October, 2011 and January-February, 2012,

2. Indian Statistical Institute, New Delhi, February, 2012.

3. Kumaun University, Almora, India, March, 2012.

Invited Lectures/Seminars:

1. *Vector Spaces*, Outreach Programme for Chennai College Lecturers, Institute of Mathematical Sciences, Chenai, May, 2011.

2. *Complex Analysis*, SPIM 2011, Harish-Chandra Research Institute, Allahabad, June, 2011.

3. *Vander Wareden and Hales-Jewitt's Theorems*, RMS workshop on Additive Combinatorics, Harish-Chandra Research Institute, Allahabad, September, 2011.

4. *Dirichlet Prime Number Theorem*, ATML School on Number Theory, Harish-Chandra Research Institute, Allahabad, January, 2012.

5. *Elliptic curves and Integer factorization*, Workshop on Number Theory and Cryptography, Indian Statistical Institute, New Delhi, February, 2012.

6. *Galois Theory*, ATML school in Galois Theory, Kumaun University, Almorah, March, 2012.

Other Activities:

1. Taught 'Analysis - I' the first year graduate course August-December, 2011.
2. Guided two first year students for their Seminar Course during August 2011 to July, 2012.
3. Organized SPIM 2011 at HRI during June, 2011.
4. Co-organizer of RMS workshop on Additive Combinatorics, September, 2011.
5. Local organizer of RMS annual meeting, October, 2011.
6. Co-organizer of International Meeting on Number Theory, December, 2011.
7. Co-organizer of ATML school on Number Theory, 2012.
8. Serving as a member of Local works committee at HRI, since august, 2011.
9. Serving as a convener of Transport committee at HRI, since august, 2011.

Manoj Kumar

Research Summary:

I (jointly with Vivek Kumar Jain and Pradeep Kumar Rai) constructed various specific examples of finite p-groups G, p an odd prime, whose automorphism group is abelian. These examples include groups G such that (i) $\gamma_2(G) = Z(G) < \Phi(G)$ and $Aut(G)$ is abelian; (ii) $\gamma_2(G) < Z(G) < \Phi(G)$ and $Aut(G)$ is abelian; (iii) $\gamma_2(G) < Z(G) = \Phi(G)$ is elementary abelian and $Aut(G)$ is elementary abelian; (iv) $\gamma_2(G) = \Phi(G) < Z(G)$ is elementary abelian and $Aut(G)$ is elementary abelian, where $Z(G)$, $\gamma_2(G)$ and $\Phi(G)$ denote the center, the commutator subgroup and the Frattini subgroup of G respectively. Such examples were not available in the literature so far (to the best of our knowledge). These examples indicate that it is difficult to put an obvious structure on the class of groups G such that $Aut(G)$ is abelian or even elementary abelian.

Let G be a group. An automorphism α of G is called class preserving if $\alpha(x)$ lies in the conjugacy class of x for all $x \in G$. An automorphism β of G is called central if it induces identity on $G/Z(G)$. I studied finite p-groups of nilpotency class 2 whose central automorphisms are all class preserving and proved, among other things, that such groups are minimally generated by even number of elements. As an application, I obtained some interesting information on finite p-groups of small orders whose automorphisms are all class preserving.

Publications:

1. Manoj K. Yadav, *Class preserving automorphisms of finite p-groups - A Survey*, Proc. Groups St. Andrews (Bath) 2009, LMS Lecture Note Series **388**, 569 - 579, (2011).

2. Vivek Kumar Jain and Manoj K. Yadav, *On finite p-groups whose automorphisms are all central*, Israel J. Math. **189**, 225 - 236, (2012).

3. V. Bardakov, A. Vesnin and Manoj K. Yadav, *Class preserving automorphisms of unitriangular groups,* Internat. J. Algebra Comput. **22**, 17 pages, (2012) (DOI: 10.1142/S0218196712500233).

Preprints:

1. Manoj K. Yadav, *On subgroups generated by small classes in finite groups*, Accepted for publication in Comm. Algebra.

2. Manoj K. Yadav, *On finite p-groups whose central automorphisms are all class preserving*, Submitted for publication.

3. Vivek Kumar Jain, Pradeep Kumar Rai and Manoj K. Yadav, *On finite p-groups with abelian automorphism group*, Submitted for publication.

Conference/Workshops Attended:

1. *International Workshop on Finite Groups and Their Automorphisms*, Turkey, June 2011.

2. *26th Annual Conference of Ramanujan Mathematical Society*, India, October 2011.

3. *The Fourth International Group Theory Conference on Iran*, Iran, March 2012.

4. *International Conference on Group Theory and Lie Theory*, India, March 2012. (As an organizer (jointly with Dr. Punita Batra)).

Visits to other Institutes:

1. IISER Mohali, India, May 2011.

2. Bogazici University, Istanbul, Turkey, June 2011.

3. Isfahan University and Payam Noor University of Isfahan, Iran, March 2012.

Invited Lectures/Seminars:

1. *On finite p-groups whose automorphisms are all central*, International Workshop on Finite Groups and Their Automorphisms, Bogazici University, Istanbul, Turkey.

2. *Central automorphisms of finite p-groups*, North Eastern Hill University, Shillong, June 2011.

3. *On finite p-groups whose central automorphisms are all class preserving*, The Fourth International Group Theory Conference on Iran, Payam Noor University, Isfahan, Iran, March 2012.

Other Activities:

1. Organised an International Conference on Group Theory and Lie Theory (GTLT2012), March 19-21, 2012 at HRI. (Jointly with Punita Batra (HRI, Allahabad)).

2. Gave an optional mini course on 'representations of finite groups' to graduate students.

3. Gave two lectures in Rajbhasha scientific workshop in Hindi at HRI, May 2011.

4. Refering work: I refereed papers for the following journals: Comm. Algebra, Indian J. Pure and Applied Mathematics, Proc. Indian Acad. Sciences (Math. Sci.), J. Algebra and its Applications, Acta Math. Sinica (English), Publ. Math. Debrecen.

5. I was a member of various committees constituted in HRI, 2011 - 2012.

Gyan Prakash

Research Summary:

Let A be a subset of integers with positive density. A result of A. Balog shows that any such set A always contains infinitely many distinct points a, b, c such that $\frac{a+b}{2}, \frac{a+c}{2}, \frac{b+c}{2} \in A$. In a work in progress, we investigate the following question, whether in any such A, we can find three distinct points a, b, c such that $\frac{a+b}{2}, \frac{a+c}{2}, \frac{b+c}{2} \in A$ as well as $\frac{a+b+c}{2} \in A$.

Conference/Workshops Attended:

1. *26th Annual Conference of Ramanujan Mathematical Society*, India, October,2011.

2. *Instructional Workshop in Additive Combinatorics*, India, September, 2011.

Visits to other Institutes:

1. IMSc, Chennai, India, February 2012,

2. IMSc, Chennai, India, October 2011.

Invited Lectures/Seminars:

1. *Counting approximate groups and clique number of random Cayley graphs*, 26th Annual Conference of Ramanujan Mathematical Society, Allahabad University and HRI, Allahabad, Allahabad University, October 2011.

2. *Sum-free sets, Birkhoff subgroup embedding and counting approximate subgroups*, International Meeting on Number Theory Celebrating the 60th Birthday of Professor R. Balasubramanian, HRI, Allahabad, December 2011.

Other Activities:

1. Along with Dr. R. Thangadurai, organised the Instructional workshop in Additive combibinatorics for Ramanujan Mathematical Society, September 2011.

Satya Deo

Research Summary:

During the academic year 2011-2012, I have continued to work on my favorite topics of algebraic topology like cohomology theory of group actions, cohomological dimension theory and spline modules. The main emphasis, however, has been around the major research project "Topological Methods in Combinatorial Mathematics" sanctioned to me by the Department of Science and Technology, Govt of Inda. In this project we have studied and worked on various aspects of the Index theory for G-spaces, topological Tverberg theorem and the topological central point theorem. We have obtained interesting results on the index of a finitistic G-space X when G is a compact Lie group acting on X without fixed point. We have also proved that the combinatorial 8-manifolds like Quaternionic projective plane on 15 vertices cannot be embedded in the 12-dimensional Euclidean space.

Publications:

1. Satya Deo, *Index of a finitistic space and a generalization of the topological central point theorem*, The journal of Ramanujan Mathematical Society, to appear, 2012

Preprints:

1. Satya Deo, *Combinatorial 8-manifolds Like Quaternionic Projective Plane and Their Embeddings*.

2. Satya Deo and V.V.Awasthi, *Homology and Dimension-Further pathological examples*, Revised.

Conference/Workshops Attended:

1. *Annual Conference of Ramanujan Mathematical Society*, HRI, Allahabad and the University of Allahabad, Sep-Oct 2011.

2. *The 77th Annual conference of the Indian Mathematical Society*, Nanded, MS, Dec 2011.

3. *International Conference on Number Theory in Honour of R.Balasubramaniam*, HRI, Allahabad, Dec 2011.

4. *National Seminar on Complex Analysis and Related Areas*, University of Jammu, Jammu, Feb 2012.

5. *Conference on Group theory and Lie Theory*, HRI, Allahabad, Feb 2012.

Visits to other Institutes:

1. University of Delhi, South Campus, New Delhi, Sep 2011.

2. Indian Statistical Institute, New Delhi Center, New Delhi, Oct 2011.

Invited Lectures/Seminars:

1. *Historical Motivations of Topology*, INSPIRE programme of DST, Swami Ramanand Teerth Maarathawada University, Nanded, Nanded, MS, March 2012

2. *Hyperbolic Geometry*, Mathematics Department Seminar, Swami Ramanand Teerth Marathawada University, Nanded, Nanded, MS, March 2012.

3. *Keynote address in the Annual Conference of Jammu Mathematical Society*, Jammu, Feb 2012

Academic recognition/Awards:

- Elected Treasurer, National Academy of Sciences, India (NASI), Allahabad, Jan 2012

- Continuing as Academic Secretary, Indian Mathematical Society, 2011-12.

Other Activities:

1. Member, Faculty of Mathematical Sciences, University of Delhi, Delhi.

2. Member, Board of Studies in Mathematics and Doctoral Research Committee, University of Allahabad, Allahabad.

Kasi Viswanadham G

Research Summary:

Florian Luca and De Konnik have proved that for any given k, There exist an integer n_k such that $\beta(n_k + 1) = \beta(n_k + 2) = \cdots = \beta(n_k + k)$ and they given upper and lower bounds for n_k, where $\beta(n)$ is the product of the exponents in the prime factorization of n. Currently I am working on this problem to improve the upper and lower bounds.

Let f be a generalized modular function (GMF) on the Hecke congruence subgroup $\Gamma_0(N)$. Jaban Meher and Kohnen proved that if f is a non constant weight zero GMF on $\Gamma_0(N)$ and suppose f has neither zeros nor poles on the upper half plane, then the sequence $\{c(n)\}_{n\geq 1}$ of fourier coefficients in the product expansion of f , changes sign infinitely often. In a joint work with Karam Deo and Jaban Meher, I am investigating the behaviour of the sign changes for the subsequence of the fourier coefficients indexed by primes $\{c(p), p \geq 2\}$. We are also investigating the behaviour of the sign changes for the subsequences $\{\lambda(n^j)\}_{n\geq 1}$ for $j = 2, 3, 4$ where $\{\lambda(n)\}_{n\geq 1}$ is the sequence of normalized fourier coefficients of a Hecke eigen form.

Apart from this I have been learning some methods from sieve theory.

Conference/Workshops Attended:

1. *International meeting on number theory*, HRI, Dec 2011.
2. *Winter school in mathematics*, IISER Kolkata, Dec 2011.

Visits to other Institutes

1. Institute of mathematical sciences, Chennai, Sep-Dec 2011.

Other Activities:

1. Gave a short course on topology in SPIM, June-July 2011.
2. Tutor in ATM school for lectures, HRI, Dec 2011.

Pradip Kumar

Research Summary:

1. Path space: If M is any finite dimensional smooth manifold, define $PM := C^\infty([0,1], M)$. This space naturally has manifold structure modelled over nuclear and dually nuclear space. In general, if N is smooth manifold with corner[arXiv:0910.3518] and M is smooth manifold(both finite dimensional), then $C^\infty(N, M)$ is nuclear Frechet manifold. Many properties has been studied by P.W. Michor in his monograph "Manifolds of Differential Mappings". $C^\infty(N, M)$ inherits many property from M, in particular if M is almost complex manifold, $C^\infty(N, M)$ is also almost complex manifold. If M is complex manifold, in general, $C^\infty(N, M)$ need not be complex manifold. We showed that $C^\infty(N, M)$ is weak integrable with induced almost complex structure.

2. One Parameter Family Of Solitons From Minimal Surfaces (joint work with Rukmini Dey): We discuss a one parameter family of complex Born-Infeld solitons arising from a one parameter family of minimal surfaces. We illustrate this with an example. We find that the action or the energy of this family of solitons remains invariant in this family and and the symmetry of the B-I equations which is responsible for it. We illustrate it with a lot of examples

Publication:

1. **Rukmini Dey, Pradip Kumar**: One Parameter Family Of Solitons From Minimal Surfaces: *it discusses various new soliton arising from minimal surface* Accepted for publication in Proceedings of Mathematical sciences, Indian academy of sciences.

Preprint:

1. **Pradip Kumar**: Almost complex structure on path spaces.

Visits to other Institutes:

1. 5 May to 14 May 2011 SN Bose National Centre of Basic sciences, Kolkata India

2. 12 March to 22 March 2012 ISI Kolkata to visit Prof. Mahuya Datta.

Other Activities:

1. Gave 3 lecture in Topology in 3 weeks SPIM program-2011 (summer program in Mathematics for Undergraduate) in Harish Chandra Research Institute Allahabad India.

2. Tutor for Topology-I course Autum 2011 for First year PhD course work.

Jaban Meher

Research Summary:

1. Rankin-Cohen brackets of eigenforms: The space of modular forms of fixed weight on the full modular group has a basis of simultaneous eigenvectors for all Hecke operators. A modular form is called an eigenform if it is a simultaneous eigenvector for all Hecke operators. A natural question to ask is whether the product of two eigenforms (which may be of different weights) is an eigenform. The question was taken up by W. Duke [In Number theory in progress, Berlin (1999), 737–741] and E. Ghate [J. Ramanujan Math. Soc. **15** (2000), 71–79]. They proved that there are only finitely many cases where this phenomenon happens. Then a more general question i.e., the Rankin-Cohen bracket of two eigenforms was studied by D. Lanphier and R. Takloo-Bighash [J. Ramanujan Math. Soc. **19** (2004), 253–259]. They also proved that except for finitely many cases, the Rankin-Cohen brackets of two eigenforms is not an eigenform. Recently, Beyerl, James, Trentacoste, Xue [Ramanujan J. **27** (2012), 377–386] have proved that this phenomenon extends to a certain class of nearly holomorphic modular forms. More explicitly, they have proved that there is only one more case apart from the cases listed by Duke and Ghate for which the product of two nearly holomorphic eigenforms of certain type is a nearly holomorphic eigenform. In this work, we consider a few more cases of such results. First, we consider the product of two quasimodular eigenforms. Secondly, we consider the product of nearly holomorphic eigenforms. Finally, we generalize the result of Ghate [Acta Arith. **102** (2002), 27–44] to the case of Rankin-Cohen brackets.

2. Theory of newforms of half-integral weight (joint work with M. Manickam and B. Ramakrishnan): Let $M = 2^a N$, N is an odd square-free positive integer, a is an integer, $0 \leq a \leq 2$. Let χ be a real Dirichlet character modulo M and χ is primitive modulo 8 if $a = 2$. By explicit computation of traces M. Ueda proved that there exists a Hecke equivariant isomorphism between the spaces $S_{k+1/2}(4M, \chi)$ and $S_{2k}(2M)$. In this work, we set up the theory of newforms for both the Kohnen plus space and the full space on these spaces $S_{k+1/2}(2^{a+2}N, \chi)$, for $0 \leq a \leq 2$ and χ is primitive modulo 8 if $a = 2$. The theory of newforms is known for the spaces when $a = 0$ by the work of W. Kohnen and Manickam-Ramakrishnan-Vasudevan. If $a = 1$ the theory is known for the full space by the work of Manickam and for the Kohnen plus space by a recent result of M. Ueda and S. Yamana. Using the Ueda's isomorphism as a main tool, we establish the theory of newforms for the remaining cases for both the Kohnen plus space and

the full space. Using the explicit dimension formulas, we observe that the Shimura maps $\mathcal{S}_{t,16N}$ maps the space $S_{k+1/2}(16N)$ into $S_{2k}(4N)$ and thereby we deduce that there is no newform space on $S_{k+1/2}(16N)$. However, we establish the theory of newforms for $S_{k+1/2}(16N, \chi)$, which is compatible with integral weight theory when χ is a primitive character modulo 8.

3. Ramanujan's proof of Bertrand's postulate (joint work with M. Ram Murty): In 1919, Ramanujan [J. Indian Math. Soc. **11** (1919), 181–182] gave a short and elegant proof of Bertrands postulate which asserts that for any $x > 1$, there is always a prime between x and $2x$. In his proof, Ramanujan uses Stirling's formula and the purpose of this work is to eliminate this step from his proof. The revised proof now is so elegant that it qualifies to be included in "Proofs from the Book". We hope that our presentation and arrangement makes Ramanujan's proof more widely known and accessible to a larger community.

Preprints:

1. Jaban Meher, *Some remarks on Rankin-Cohen brackets of eigenforms,* Accepted for publication in International Journal of Number Theory.

2. M. Manickam, Jaban Meher and B. Ramakrishnan, *Newforms of half-integral weight on* $\Gamma_0(8N)$ *and* $\Gamma_0(16N)$, Preprint.

3. Jaban Meher and M. Ram Murty, *Ramanujan's proof of Bertrand's postulate,* Preprint.

Conference/Workshops Attended:

1. *International Meeting on Number Theory, Celebrating the 60th Birthday of Professor R. Balasubramanian*, HRI, Allahabad, India, December 2011.

2. *International Colloquium on Automorphic representations and L-functions*, TIFR, Mumbai, India, January 2012.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, October 2011.

Invited Lectures/Seminars:

1. *On generalized modular forms*, HRI, Allahabad, India, August 2011.

Other Activities:

1. Gave a course in Algebra in SPIM, HRI, Allahabad, June, 2011.
2. Gave lectures on Modular forms in ATM School for Lecturers in Number Theory, HRI, Allahabad, December, 2011.

Jay Gopalbhai Mehta

Research Summary:

In a joint work with Prof. Kalyan Chakraborty, we proposed a stamped blind signature scheme based on elliptic curve discrete log problem and hash functions. We also studied couple of well-known key exchange cryptographic protocols. We suggested an alternative way to prevent the 'unknown-key share attack' on these protocols using cryptographic biliear maps by adding a third pass.

Another joint work with Prof. Kalyan Chakraborty includes the study of complex valued completely multiplicative functions satisfying some special properties.

Work is in progress to determine additive functions, on the ring of integers of imaginary quadratic fields, having constant values on some discs in the complex plane.

Publications:

1. Kalyan Chakraborty and Jay Mehta, *A Stamped Blind Signature Scheme based on Elliptic curve Discrete Log Problem,* accepted in International Journal of Network Security.

2. Kalyan Chakraborty and Jay Mehta, *On completely multiplicative complex valued funtions,* accepted in Annales Uni. Sci. Budapest. Sectio Comput.

Preprints:

1. Kalyan Chakraborty and Jay Mehta, *Preventing Unknown Key Share attack using Cryptographic Bilinear Maps,* HRI-M-12-04-003.

Conference/Workshops Attended:

1. *Lectures on Introduction to Theory of Numbers*, Nepal, November, 2011.

2. *International Meeting on Number Theory*, Allahabad, India, December, 2011.

Visits to other Institutes:

1. Department of Mathematics, Tribhuvan University, Kirtipur, Nepal, November 2011.

Invited Lectures/Seminars:

1. *Basic Topology*, Summer Program in Mathematics (SPIM 2011), Harish Chandra Research Institute, Allahabad, June 2011.

2. *Tutorials on "Introduction to Theory of Numbers"*, A course on "Introduction to Theory of Numbers", Department of Mathematics, Tribhuvan University, Kirtipur, Nepal, November 2011.

3. *Tutorials on Number Theory*, Advanced Training Schools in Mathematics for Lectures (ATML), Harish Chandra Research Institute, Allahabad, Dec-Jan 2012.

Other Activities:

1. Compiled HRI Annual Report for the academic year 2010-2011, May-June 2011.

P. Akhilesh

Research Summary:

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

I have obtained an explicit version, with a different proof, of the large sieve inequality in several dimensions given by L. Zhao in "An improvement of the large sieve inequality in high dimensions" Mathematika, 2005.

It has recently been shown by D.S. Ramana and O. Ramaré that given any colouring of the sequence of primes in K colours, every sufficiently large integer admits a monochromatic representation as a sum of primes in no more than $CK \log\log 4K$ terms. I am studying the analogous question for representation by squares.

Preprints:

1. P. Akhilesh and D.S. Ramana, *A Remark on the Buerling Selberg Function,* submitted.

Conference/Workshops Attended:

1. *Workshop on Functional Analysis and Harmonic Analysis*, Kerala School of Mathematics, Kozhikode, June 2011

2. *Instructional Workshop on Ergodic Theory*, Kerala School of Mathematics, Kozhikode, October 2011

3. *International conference on Numbertheory*, HRI Allahabad , December 2011

4. *ATML workshop in Numbertheory*, HRI Allahabad, December 2011

5. *"Panorama Lectures", Prof. Ram Murty from Queens University, Canada delivered a series of lectures on Ramanujan and L-functions*, Kerala School of Mathematics, Kozhikode, May 2012.

6. *Workshop on Theory of Prime Numbers and related areas.*, Kerala School of Mathematics, Kozhikode, May 2012.

Visits to other Institutes:

1. Kerala School of Mathematics, Kozhikode, August to November, 2011.
2. I.M.Sc., Chennai, November, 2011.

Other Activities:

1. Lectured on the large sieve at the ATML workshop in Number Theory, HRI Allahabad, December, 2011.

Pradeep Kumar Rai

Research Summary:

This year, I have been studying finite p-groups G, p an odd prime, whose automorphism group is abelian. A published conjecture says that such groups must be special. Though the conjecture was disproved earlier, we (Jointly with Manoj Kumar Yadav and Vivek Kumar Jain) have tried to investigate if some weaker forms of the conjecture hold true. We also have tried to get some structural information about p-groups G, whose automorphism group is elementary abelian.

Preprints:

1. VIVEK K. JAIN, PRADEEP K. RAI and MANOJ K. YADAV, *On finite p-groups with abelian automorphism group.*

Conference/Workshops Attended:

1. *26th Annual Conference of Ramanujan Mathematical Society* , India, October 2011.
2. *International Conference on Group Theory and Lie Theory*, India, March 2012.
3. *International Meeting on Number Theory*, India, December 2011.

Invited Lectures/Seminars:

1. *On finite p-groups with abelian automorphism group*, International Conference on Group Theory and Lie Theory, Harish Chandra Research Institute, Allahabad, March 2012.

Other Activities:

1. Gave three lectures in SPIM at HRI, June 2011.

Karam Deo Shankhadhar

Research Summary:

1. Restriction map for Jacobi forms (joint work with B. Ramakrishnan): Let D_0 be the restriction map from the space of Jacobi forms of weight k, index m on the congruence subgroup $\Gamma_0(N)$ to that of elliptic modular forms of the same weight on $\Gamma_0(N)$, given by $\phi(\tau, z) \mapsto \phi(\tau, 0)$. More generally, one obtains modular forms of weight $k+\nu$ by using certain differential operators D_ν. Then it is known that $\oplus_{\nu=0}^{m} D_{2\nu}$ is injective for k even, but when $k \geq 4$, it is well-known that the map D_0 is far from being injective. However, J. Kramer and T. Arakawa & S. Böcherer observed that when $k = 2$ the situation may be different. In fact, when $m = 1$, Arakawa and Böcherer provided two explicit descriptions of $\mathrm{Ker}(D_0)$: one in terms of modular forms of weight $k-1$ and the other in terms of modular forms of weight $k+2$ (by applying the differential operator D_2 on $\mathrm{Ker}(D_0)$). In a subsequent paper, they proved that D_0 is injective in the case $k = 2$, $m = 1$ and gave some applications.
In this work, we generalize the results of Arakawa-Böcherer to higher index. First, we consider the case $m = 2$ and show that $\mathrm{Ker}(D_0)$ is isomorphic to the space of vector-valued modular forms of weight $k-1$ and $D_2(\mathrm{Ker}(D_0))$ is isomorphic to a certain subspace of cusp forms of weight $k+2$ and these two spaces are related with each other by a simple isomorphism. Next, we obtain the injectivity of $D_0 \oplus D_2$ on $J_{2,2}(\Gamma_0(2N))$, where $N = 2$ or an odd square-free positive integer. Next, we consider a subspace of $J_{k,m}(\Gamma_0(mN), \chi)$, where m is a square-free positive integer and N is any positive integer and obtain results similar to Arakawa-Böcherer and prove the injectivity of D_0 on this subspace when $k = 2$, mN square-free. At the end we make several remarks concerning the subspace studied in our work.

2. Non-vanishing of L-functions of half-integral weight (joint work with B. Ramakrishnan): In 1997, W. Kohnen showed that a certain average of L-functions over a basis of cusp forms of integral weight on $\mathrm{SL}_2(\mathbf{Z})$ does not vanish in large parts of the critical strip. As a consequence, he proved that for any point s inside the critical strip not lying on the line $\mathrm{Re}(s) = k/2$, there exists a Hecke eigen cusp form of integral weight k on $SL_2(\mathbf{Z})$, such that the corresponding L-function value at s is non-zero for sufficiently large k. In 2005, A. Raghuram generalised Kohnen's method for the average of L-functions over a basis of newforms (of integral weight) of level N with primitive character modulo N. In this article, we extend Kohnen's method to forms of half-integral weight. As a consequence, we

show that for any given point s inside the critical strip not lying on the line $\mathrm{Re}(s) = k/2 + 1/4$, there exists a Hecke eigen cusp form f of half-integral weight $k + 1/2$ on $\Gamma_0(4N)$ with character ψ such that the corresponding L-function value at s is non-zero, and the first Fourier coefficient of f is non-zero. Our results are obtained for N sufficiently large if k is fixed and vice versa. In particular when $N = 1$, for sufficiently large k, either f is a newform in the full space or f is a Hecke eigenform in the Kohnen plus space. It should be noted that the normalisation of Fourier coefficients of forms of half-integral weight is still an open question.

3. Correspondence between higher degree Jacobi forms and modular forms of integral weight (joint work with B. Ramakrishnan): In [Invent. Math. **94** (1988)], N. -P. Skoruppa and D. Zagier constructed certain lifting maps (Shimura type correspondence) between the space of Jacobi cusp forms of integral weight and a subspace of cusp forms of integral weight. Further, in [Math. Ann. **278**(1987)], B. Gross, W. Kohnen and D. Zagier constructed a kernel function for these liftings. By using these correspondences, they obtained deep formulas relating to the height pairings of Heegner points to the Fourier coefficients of Jacobi forms. This correspondence for the general level (for subgroups of the full Jacobi group) was generalized by B. Ramakrishnan in his thesis. In [Trans. Amer. Math. Soc. **352** (2000)], the same results were obtained by M. Manickam and B. Ramakrishnan by showing that the image of the Poincaré series under the Shimura map can be expressed in terms of the holomorphic kernels of the periods of cusp forms. In [Math. Z. **253** (2006)], K. Bringmann generalized these liftings to Jacobi forms of higher degree (in particular to Jacobi forms on $\mathcal{H} \times \mathbf{C}^g$ with matrix index of size g) on the full Jacobi group. In this work, we generalize the results of K. Bringmann for Jacobi forms of integral weight and matrix index for the congruence subgroups of the full Jacobi group by adopting the techniques of [Trans. Amer. Math. Soc. **352** (2000)]. By using the earlier correspondences together with our work, we obtain a correspondence between Jacobi forms of higher degree (matrix index) and Jacobi forms of degree 1 (integer index). Further work is in progress.

Preprints:

1. B. Ramakrishnan and Karam Deo Shankhadhar, *On the restriction map for Jacobi forms* (submitted for publication).

2. B. Ramakrishnan and Karam Deo Shankhadhar, *Non-vanishing of L-functions associated to cusp forms of half-integral weight inside the critical*

strip (submitted for publication).

3. B. Ramakrishnan and Karam Deo Shankhadhar, *On a correspondence between Jacobi cusp forms and elliptic cusp forms* (preliminary version).

Conference/Workshops Attended:

1. *International colloquium on Automorphic representations and L-functions*, 3-11 January 2012, TIFR, Mumbai, India.

2. *International meeting on Number theory celebrating the 60th birthday of Prof. R. Balasubramanian*, 15-20 December 2011, HRI, Allahabad, India.

Visits to other Institutes:

1. The Institute of Mathematical Sciences, Chennai, India, 12-29 October 2011.

Other Activities:

1. Took tutorial classes in the ATM school for lecturers in Number theory (Modular form), Harish-Chandra Research Institute, Allahabad, December 2011.

2. Taught a course on Elementary Number Theory in the Summer Programme in Mathematics, Harish-Chandra Research Institute, Allahabad, June-July 2011.

3. Helped in organizing HRI Science talent test, 2011 (Mathematics).

Vijay Kumar Sohani

Research Summary:

We obtain homogeneous Strichartz estimate for the Schrödinger propagator e^{-itL_α} for the Laguerre operator L_α on $\mathbb{R}^n_+$. We also establish inhomogeneous Strichartz estimates for different admissible pairs. Strichartz estimates are useful for solving semilinear Schrödinger and wave equations, in which no derivatives are present in the nonlinearity. Strichartz estimates were first proved by Strichartz (1977) for solutions of Schrödinger and wave equations on $\mathbb{R}^n$.

Preprints:

1. V. K. Sohani, *Strichartz Estimates for the Schrödinger propagator for the Laguerre Operator* (in preparation).

2. V. K. Sohani and P. K. Ratnakumar, *Non linear Schrödinger equation for the twisted Laplacian,* arxiv: http://128.84.158.119/abs/1204.1843

Conference/Workshops Attended:

1. *ATM Workshop on Lie Groups and Lie Algebras*, HRI Allahabad, India, 22-27 August, 2011.

2. *Twelfth Discussion Meeting in Harmonic Analysis*, ISI, Kolkata, India, 27-29 December, 2011.

3. *School and Workshop on Cocompact Imbeddings, Profile Decompositions, and their Applications to PDE*, TIFR Bangalore, India, 03-12 January, 2012.

4. *ATMW Harmonic Analysis*, IIT Kanpur, India, 16-21 January, 2012.

5. *Discussion Meeting on Analysis and Geometry*, HRI Allahabad, India, 12-16 March, 2012.

Invited Lectures/Seminars:

1. *Non linear Schrödinger equation for the special Hermite operator*, Twelfth Discussion Meeting in Harmonic Analysis, ISI, Kolkata, India, 27-29 December, 2011.

Umesh Vanktesh Dubey

Research Summary:

The moduli of sheaves on a projective scheme are interesting class of examples of higher dimensional schemes. These examples are also useful in classification of schemes. Classically the moduli spaces of vector bundles on algebraic curves were constructed and studied by Mumford and Seshadri. Alvaréz-Consul and King have given a new approach to construct moduli of sheaves on higher dimensional projective schemes using moduli of representations of Kronecker algebras. In collaboration with Raghavendra we are trying to use this construction of moduli to study various structures on moduli of sheaves.

Publications:

1. Umesh Dubey, Amritanshu Prasad and Pooja Singla, *The Cartan matrix of a centralizer algebra,* Proc. Indian Acad. Sci. (Math. Sci.) **122(1)**, 67-73, (2012)

Preprints:

1. Umesh Dubey and Vivek Mallick, *Spectrum of Some Triangulated Categories ,* arXiv:1012.0789

2. Umesh Dubey and Vivek Mallick, *Reconstruction of a Superscheme from its Derived Category*

Conference/Workshops Attended:

1. *CMI-IMSC Colloquium*, Chennai, India, January, 2012.

2. *International Conference on Commutative Algebra and Algebraic Geometry*, Puducherry, India, March 2012.

Invited Lectures/Seminars:

1. *Spectrum of tensor triangulated categories* , CAAG 2012, Pondicherry University, Puducherry, March 2012.

Saikat Chatterjee

Research Summary:

I have joined Mathematics department on 1st December, 2011. Before that I worked with Indranil Biswas in School of Mathematics, TIFR. We have studied almost generalized complex structure on path spaces and flat connections on a punctured manifold of genus g.

Currently I am working with Rukmini Dey (HRI, India) and Indranil Biswas(TIFR, India) on the Poisson structure and quantization problem on path spaces. We are writing a paper on the topic.

In collaboration with Amitabha Lahiri (SNBNCBS, India) and Ambar Sengupta(LSU, USA) I am studying categorical bundle structure and representation of categorical groups. A paper on the subject of categorical bundle and another one on monoidal structure of double categories have been submitted for publication.

Publications:

1. Indranil Biswas, Saikat Chatterjee *Flat connections on punctured surfaces and geodesic polygons in a Lie group,* Bull. des Sciences Math. **136**, 37-43, (2012)

Preprints:

1. Saikat Chatterjee, Amitabha Lahiri, Ambar Sengupta *A Morphism Double Category and Monoidal Structure* (communicated) http://arxiv.org/abs/1205.3565
2. Saikat Chatterjee, Amitabha Lahiri, Ambar Sengupta *Categorical geometry in gauge theories* (communicated) (preprint)
3. Indranil Biswas, Saikat Chatterjee, Rukmini Dey *Poisson structure and quantization on path spaces* (tentative title) (in preparation)
4. Saikat Chatterjee, Amitabha Lahiri, Ambar Sengupta *Representations of categorical groups* (tentative title)(in preparation)

Visits to other Institutes:

1. S. N. Bose National Centre for Basic Sciences, Kolkata, India, 20-29 th February, 2012

Ashwin Subodh Pande

Research Summary:

From Aprll 2011 to January 2012, I completed a paper 'Topological T-duality and Automorphisms' which began as part of my Ph.D. Thesis. It has been submitted to *The Journal of Geometry and Physics* for refereeing. A brief outline of the paper follows.

Let W be a CW-complex. I extend the formalism of Topological T-duality to spaces which are the total space of a principal S^1-bundle $p : E \to W$ with a cohomology class termed the $H-$flux in $H^3(E, \mathbb{Z})$ together with an automorphism of the continuous-trace algebra on E determined by H. The automorphism is a 'topological approximation' to a gerby gauge transformation of spacetime. I motivate this physically from Buscher's Rules for T-duality. Using the Equivariant Brauer Group, I connect this problem to the C^*-algebraic formalism of Topological T-duality of Mathai and Rosenberg [1].

I show that the study of this problem leads to the study of a purely topological problem, namely, Topological T-duality of triples (p, b, H) consisting of isomorphism classes of a principal circle bundle $p : X \to B$ and classes $b \in H^2(X, \mathbb{Z})$ and $H \in H^3(X, \mathbb{Z})$. I construct a classifying space $R_{3,2}$ for triples in a manner similar to the work of Bunke and Schick [2]. I characterize $R_{3,2}$ up to homotopy and study some of its properties. I show that it possesses a natural self-map which induces T-duality for triples. I study some properties of this map.

I plan to work further on some topics in Topological T-duality which interest me. In particular I am trying to calculate the T-dual of a Semi-Free S^1-space using methods from stack theory as outlined in Refs. [3, 4].

Preprints:

1. Ashwin S. Pande, *Topological T-duality, Automorphisms and Classifying Spaces* submitted to *Jour. Geom. Phys.* for refereeing.

Invited Lectures/Seminars:

1. Topological T-duality, Mathematics Seminar, HRI, HRI, April 2011.
2. Topological T-duality, Automorphisms and Classifying Spaces, Renewal Seminar, HRI, HRI, January 2012.

Bibliography

[1] Varghese Mathai, Jonathan Rosenberg, 'T-duality for torus bundles via noncommutative topology', *Commun. Math. Phys.*, **253**, 705-721, (2005); also at `arXiv:hep-th/0401168`.

[2] Ulrich Bunke, Thomas Schick, 'On the topology of T-duality', *Rev. Math. Phys.*, **17:**77-112, (2005); also at `arXiv:math/0405132`.

[3] Ulrich Bunke, Thomas Schick, 'T-duality for non-free circle actions', *Analysis, geometry and topology of elliptic operators*, **429–466**, World Sci. Publ., Hackensack, NJ, (2006); also at `arXiv:math/0508550`.

[4] Ulrich Bunke, Markus Spitzwek, Thomas Schick, 'Periodic Twisted Cohomology and T-duality', *Asterisque*, **337**, (2011); also at `arXiv:0805.1459`.

On Bilinear Littlewood-Paley Square Functions

Saurabh Kumar Shrivastava

Research Summary:

My research interest lies in Euclidean harmonic analysis. Currently, I am interested in the theory of bilinear multipliers, which is among the most active research areas in harmonic analysis.

Let $\{\omega_l\}_{l\in\mathbb{Z}}$ be a sequence of disjoint intervals in $\mathbb{R}$. For $f, g \in S(\mathbb{R})$, non-smooth bilinear Littlewood-Paley square function associated with the sequence $\{\omega_l\}_{l\in\mathbb{Z}}$ is defined as:

$$S(f,g)(x) \;=\; \left(\sum_{l\in\mathbb{Z}} |S_{\omega_l}(f,g)(x)|^2\right)^{\frac{1}{2}},$$

where S_{ω_l} is the bilinear operator associated with the symbol $\chi_{\omega_l}(\xi-\eta)$, i.e.,

$$S_{\omega_l}(f,g)(x) := \int_{\mathbb{R}}\int_{\mathbb{R}} \hat{f}(\xi)\hat{g}(\eta)\chi_{\omega_l}(\xi-\eta)e^{2\pi i x(\xi+\eta)}d\xi d\eta.$$

The smooth bilinear square functions are defined similarly. More precisely, for a sequence of disjoint intervals ω_l in $\mathbb{R}$, smooth bilinear square function is defined as

$$T(f,g)(x) := \left(\sum_{l\in\mathbb{Z}} |T_{\phi_l}(f,g)(x)|^2\right)^{\frac{1}{2}},\ f,g\in S(\mathbb{R}),$$

where T_{ϕ_l} is the bilinear multiplier operator associated with smooth symbol $\phi_l(\xi-\eta)$ with $supp(\phi_l)\subset\omega_l$.

We have studied L^p-boundedness properties of bilinear smooth square functions.

Let ϕ be a smooth function defined on $\mathbb{R}$ such that ϕ is supported in the unit interval of $\mathbb{R}$. For $l\in\mathbb{Z}$, let ϕ_l be the function defined by $\phi_l(\xi) = \phi(\xi-l)$. Then, we proved that for all expoents p,q,r satisfying $2\le p,q\le\infty$ and $\frac{1}{p}+\frac{1}{q}=\frac{1}{r}$, there exists a constant $C>0$ such that for all $f,g\in\mathcal{S}(\mathbb{R})$ we have

$$\|T(f,g)\|_{L^r(\mathbb{R})} \;\le\; C\|f\|_{L^p(\mathbb{R})}\|g\|_{L^q(\mathbb{R})}.$$

The condition $p,q\ge 2$ is a necessary condition.

We also studied analogous bilinear square functions on the Torus group $\mathbb{T}$. Moreover, our result is valid in higher dimensional setting as well.

This is a joint work with P. K. Ratnakumar. In this work, we have extended some results of M. Lacey; P. Mohanty and S. Shrivastava on bilinear square functions to all possible values of exponents p, q, r.

Publications:

1. Saurabh Shrivastava and P. K. Ratnakumar, *On bilinear Littlewood-Paley square functions,* Proc. Amer. Math. Soc. to appear.

Conference/Workshops Attended:

1. *Discussion Meeting on Analysis and Geometry*, HRI Allahabad, India, March 2012

Visits to other Institutes:

1. Indian Institute of Technology Kanpur, Kanpur, India, May 2011.
2. Indian Institute of Science Bangalore, Bangalore, India, July 2011.
3. Indian Institute of Technology Kanpur, Kanpur, India, January 2012.

Lectures/Seminars:

1. *A series of five lectures on bilinear Littlewood-Paley square functions* at Department of Mathematics, IISc Bangalore, Bangalore, July 2011.
2. *A series of three lectures on classical Littlewood-Paley theory*, for ATM School on harmonic analysis held at the Department of Mathematics, IIT Kanpur, Jan 9-21 2012.

Academic Report - Physics

Anirban Basu

Research Summary:

My main research interest has been to analyze the effective action of string theory in specific backgrounds, where certain higher derivative terms can be explicitly calculated. I have worked on this problem in the context of type IIB string theory compactified on T^2, where I considered a class of eight derivative terms. These 1/2 BPS interactions have moduli dependent couplings. I imposed the constraints of supersymmetry to show that each of these couplings satisfy a first order differential equation on moduli space which relate it to other couplings in the same supermuliplet. These equations can be iterated to give second order differential equations for the various couplings. The couplings which only depend on the $SO(2)\backslash SL(2,R)$ moduli satisfy Laplace equation on moduli space, and are given by modular forms of $SL(2,Z)$. On the other hand, the ones that only depend on the $SO(3)\backslash SL(3,R)$ moduli satisfy Poisson equation on moduli space, where the source terms are given by other couplings in the same supermultiplet. The couplings of the interactions which are charged under $SU(2)$ are not automorphic forms of $SL(3,Z)$. Among the interactions I considered, the R^4 coupling depends on all the moduli.

Publications:

1. Anirban Basu, *Supersymmetry constraints on the R^4 multiplet in type IIB on T^2* Class. Quant. Grav. **28**, 225018, (2011)

Conferences/Workshops Attended:

1. *National Strings Meeting*, Delhi University, New Delhi, December, 2011

2. *The Mathematics and Applications of Branes in String and M-Theory*, Newton Institute, Cambridge, UK, March 2012

Visits to other Institutes:

1. Institute of Physics, Bhubaneswar, March 2012

2. Newton Institute, Cambridge, UK, March 2012

Invited Lectures/Seminars:

1. *Constraining the R^4 multiplet in type IIB on T^2*, Delhi University, December 2011

2. *The Effective Action in String Theory*, Utkal University, Bhubaneswar, March 2012

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

Sandhya Choubey

Research Summary:

Tremendous success of neutrino experiments in the last few decades has propelled neutrino physics to the centre stage of particle physics. The last year saw a series of new results in this field which measured one of the last missing pieces of the neutrino puzzle, the mixing angle θ_{13}, and further cemented our understanding of this subject. Current interest in this field resolves around the calculation of the physics reach of the forthcoming and proposed experiments as well as in building a model of elementary particles which would be able to incorporate observation of neutrino masses and mixing in addition to all other observations. The standard model of particle physics fails to provide a suitable explanation for the neutrino masses and mixing pattern. A natural explanation for such tiny neutrino masses is provided by postulating an effective 5-dimensional operator, the only one consistent with the SM, leading to Majorana neutrino masses suppressed by a high mass scale. In the see-saw mechanism, such an operator is generated when a heavy particle gets integrated out from the theory, where, under the SM gauge group $\mathrm{SU(2)}_L \times \mathrm{U(1)}_Y$, the heavy particle can either be a singlet fermion with $Y = 0$, a triplet scalar with $Y = 2$, or a triplet fermion with $Y = 0$. The three cases are known as the type I, type II, or type III see-saw mechanisms, respectively.

An even more fundamental question is whether the neutrinos are Dirac or Majorana particles. If neutrinos were to be Majorana particles, lepton number would be violated. Since lepton number is an accidental symmetry of the standard model of particle physics, one would like to know the scale of lepton number violation, if any, leading to the generation of neutrino masses. In addition, the peculiar pattern of neutrino masses and mixing demands an explanation which requires the extension of the standard model, and one would like to probe the existence of new particles usually considered within such extensions. While neutrino oscillations and beta decay experiments continue to improve our knowledge of the low energy neutrino mass matrix, we have to look at data from a variety of complementary avenues such as neutrinoless double beta decay experiments, lepton flavor violation searches, as well as collider experiments to augment our understanding of the mechanism responsible for neutrino mass generation. On the experimental side, there are realistic prospects for order-of-magnitude improvements in the search for the neutrinoless double beta decay half-life. We discuss neutrinoless double beta decay and lepton flavor violating decays in the colored seesaw scenario. In this

mechanism, neutrino masses are generated at one-loop via the exchange of TeV-scale fermionic and scalar color octets. The same particles mediate lepton number and flavor violating processes. We show that within this framework a dominant color octet contribution to neutrinoless double beta decay is possible without being in conflict with constraints from lepton flavor violating processes. We furthermore compare the "direct" color octet contribution to neutrinoless double beta decay with the "indirect" contribution, namely the usual standard light Majorana neutrino exchange. For degenerate color octet fermionic states both contributions are proportional to the usual effective mass, while for non-degenerate octet fermions this feature is not present. Depending on the model parameters, either of the contributions can be dominant.

Very large detected value of the third mixing angle θ_{13} has opened up our chances of observing the neutrino mass hierarchy and testing CP violation in the lepton sector. There is an international effort towards building of neutrino facilities for nailing down these remaining pieces of the neutrino puzzle. I have been involved with the the International Design Study for the Neutrino Factory, and the Interim Design Report was completed and submitted during the last academic year. I was also a part of the LENA collaboration, which completed its white paper on the feasibility and reach of the this very large neutrino detector.

Publications:

1. Sandhya Choubey, *Physics with India-based Neutrino Observatory,* AIP Conf.Proc. **1405**, 323, (2011)

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

3. Sandhya Choubey, Thomas Schwetz, Patricia Vahle, *Summary of the Oscillation Physics Working Group,* AIP Conf.Proc. **1382**, 77, (2011)

4. Sandhya Choubey, Pasquale Migliozzi, *Branch III: Oscillations at high energies*, Nucl.Phys.Proc.Suppl. **217**, 371, (2011)

5. LENA Collaboration, *The next-generation liquid-scintillator neutrino observatory LENA*, Astropart.Phys. **35**, 685, (2012)

Preprints:

1. IDS-NF Collaboration (S. Choubey et al.). *International Design Study for the Neutrino Factory, Interim Design Report*, e-Print: arXiv:1112.2853 [hep-ex]

Conference/Workshops Attended:

1. *NuInt 2011, Seventh International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region*, India, March 2011.

Invited Lectures/Seminars:

1. *Plenary talk at NuInt 2011, Seventh International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region*, Physics with INO, NuInt 2011, Dehradun, March 2011.

Academic recognition/Awards:

- PI of Joint research proposal under Indo-German (DST-DFG) S&T Cooperation Programmme, 2010-2013.
- PI of the HRI node of the ITN project Invisibles. Invisibles is a new European ITN project (FP7-PEOPLE-2011-ITN, PITN-GA-2011-289442-INVISIBLES (April 2012-March 2016)), which focuses on Neutrino and Dark Matter phenomenology and their connection. Experimental and theoretical aspects are also encompassed. The network involves nodes in seven European countries and its associated partners extend to seven non-European countries.

Other Activities:

1. Organizing schools/conferences:
   (a) Member of the organizing committee of "NuHoRIzons, Neutrinos in Physics, Astrophysics and Cosmology", held at HRI, Allahabad, January 2010.
2. Teaching at HRI: Course on "Mathematical Methods II, 2012.
3. Mentoring PhD Students:
   (a) Ram Lal Awasthi

(b) Anushree Ghosh

4. Mentoring Project Students:

   (a) Anu Alphonsa Tom, Pondichery Central University

5. Reviewing Papers: Refereed papers for

   (a) Physical Review D

6. Committees Served:

   (a) Sports and Entertainment (Convenor)
   (b) Office and Furniture Committee (Member)
   (c) Women Grievance Cell (Convenor)

Tapas Kumar Das

Research Summary:

My work during the academic year 2011 - 2012 was essentially focused on three different fields – high energy and relativistic astrophysics, emergent gravity, phonon quantization and corresponding Hawking process, and the study of non linear phenomena and onset of chaos as realized in dynamical systems subjected to the strong gravitational field.

Blandford-Znajek (BZ) process of the extraction of the rotational energy of Kerr black holes is considered to be one of the foundation stones in the development of the contemporary relativistic astrophysics. On obvious ground, the Penrose process as well as the Kerr-Newman Penrose process have fallen out of favour in comparison to the BZ process when a robust and efficient physical mechanism is sought to explain the power output of the most energetic sources in the Universe, the QSOs and GRBs for example, as well as for other typical host galaxies. In existing literature, BZ mechanism has usually been studied for cold Keplerian disc forming high angular momentum accretion or for geometrically thick radiatively inefficient ADAF. For the supermassive black holes (SMBH) at the heart of the nearby elliptical galaxies as well as for our Galactic centre SMBH, low angular momentum accretion with very rich dynamical structure is prevalent. For the first time in literature, we calculate the energy extraction (through BZ process) efficiency for low angular momentum general relativistic multi-critical accretion in Kerr metric for both the prograde as well as for the retrograde flow. Our novel approach provides the jet efficiency factor that is in exceptionally good agreement with the observational results obtained by CHANDRA observation of elliptical galaxies.

During last two years, the nearby low red shift ($z = 0.042$) narrow-line Seyfert 1 galaxy RE J1034+396 has attracted substantial attention within the high energy astrophysics community since this source was discovered to be the first ever AGN candidate showing a Quasi Periodic Oscillation (QPO) in its variability power spectrum – especially a strong QPO in the 0.3 - 10 keV X ray flux as observed by the XMM-Newton X ray satellite. In a series of papers, we made successful attempts to understand the complex nature of such QPO phenomena through the wavelet analysis favouring the linear structures – shocks, spiral waves, or distant flares, for example. We find a drift in the QPO central frequency correlated with the X ray flux with a short time delay. This indicates that such QPO spectra can be used as a diagnostic tool to understand the properties of matter in strong grav-

ity, i.e., at the close proximity of the black hole event horizon. Hence our work is useful to probe the strong gravity black hole space-time through the study of the QPO phenomena as observed in AGN candidates.

A SMBH with mass $\sim 4.4 \times 10^6 M_\odot$ resides at the heart of our Milky way – at the Sagittarius A* (SgrA*) radio source, to be more specific. The low luminosity underfed SMBH at SgrA* remains in a very quiet state as implied by the measurement of the corresponding Faraday rotation. SgrA* SMBH is surrounded by a 'mini - spiral' aka SgrA west complex which is situated at a distance $0.06\ pc$ (projected distance) away from the central SMBH. The mini-spiral is composed of cosmic gas and dust of rather complex composition, and is resolved as a three armed structure of clumpy material that is in quasi Keplerian motion. Recent INTEGRAL and XMM-Newton observations of the X ray reflections from the molecular cloud surrounding the SgrA* as reported during the year $\sim$ 2010 - 2011 revealed that SgrA* was several order of magnitude brighter only a few hundred years ago and hence unlike the present scenario, the activities at our Galactic centre was in quite a 'rebellious' form during that time. This has been a remarkable discovery raising the theoretical question as what physical phenomena was responsible to make a quiescent state black hole to vigorously 'flare up'. Using a novel analytical approach we show how the flow of hot gas from the colliding arms or the mini spiral proceeded through a transient geometrically thick axially symmetric configuration could sustain the luminosity of the SgrA* in its late time bright state.

We introduces a novel formalism to investigate the role of the spin angular momentum of astrophysical black holes in influencing the dynamical and radiative behaviour of general relativistic accretion at a very close proximity of the event horizon. We consider a four dimensional stationary axisymmetric spacetime with two commuting Killing vector fields and take general relativistic Euler and continuity equations. We have been able to show using symmetry arguments that if we restrict our attention to dimension three, this flow equation is completely separable analytically and by specifying the equation of state, we can completely determine the components of the fluid velocity. This can be considered as a general framework for dealing with the fluid equations in rotating black hole spacetimes. We then provide the critical solutions for the stationary flow. By introducing a linearized perturbation scheme, we demonstrate that such transonic stationary solutions are stable. The properties of infalling material, for the prograde as well for the retrograde accretion, extremely close to the event horizon are studied as a function of the Kerr parameter, leading to the possibility of identifying a new spectral signature of black hole spin.

The possibility of performing the black hole shadow imaging using direct VLBI measurement will also be explored.

One of our recent works makes the first ever attempt to understand the influence of the black hole background spacetime in determining the fundamental properties of the embedded relativistic acoustic geometry. To accomplish such task, the role of the spin angular momentum of the astrophysical black hole (the Kerr parameter a – a representative feature of the background black hole metric) in estimating the value of the acoustic surface gravity (the representative feature of the corresponding analogue space time) has been investigated. Since almost all astrophysical black holes are supposed to posses some degree of intrinsic rotation, the influence of the black hole spin on classical analogue models is extremely important to understand. For certain values of the initial boundary conditions, more than one acoustic horizons, namely two black hole type and one white hole type, may form, where the surface gravity may become formally infinite at the acoustic white hole. The connection between the corresponding analogue Hawking temperature with astrophysically relevant observables associated with the spectral signature has been realized.

In a related work, we investigate the influence of the background flow configuration on determining the salient features of the corresponding acoustic geometry for axially symmetric flow of dissipationless inhomogeneous fluid onto a non rotating astrophysical black hole under the influence of a generalized pseudo-Schwarzschild gravitational potential. The dependence of the acoustic surface gravity and the analogue Hawking temperature on the geometric configuration as well as on various accretion variables has been studied completely analytically.

For general relativistic axisymmetric flow of compressible fluid in the Schwarzschild metric, we employ the theory of algebraic polynomials to analytically investigate the multi-critical flow behaviour and apply certain techniques of catastrophe theory to study the corresponding saddle-centre bifurcation phenomena. Our work can further be generalized to analytically calculate the maximally allowed number of the equilibrium points certain autonomous dynamical system can have.

We investigate the particle dynamics in black hole space time where the potential of the host galaxy acts as a reflection symmetry breaking perturbing agent. Introduction of such dipole or higher order (quadrupole/octupole) perturbing potential is responsible for the particle to make transition from the regular to the chaotic orbit. We study the Poincaré sections to look for the signature of such transition, and try to understand the physical

nature of the perturbing potential from the dynamical trajectories. Our initial findings (results not yet communicated) suggests that the degree of chaotic motion is maximum for a Schwarzschild black hole and minimum for an extremally rotating black hole.

Publications:

1. Tapas Kumar Das & Bożena Czerny, *On the efficiency of the Blandford-Znajek mechanism for low angular momentum relativistic accretion,* Monthly Notices of the Royal Astronomical Society Letters **421**, L24, (2011)

2. Shilpi Agarwal, Tapas Kumar Das, Rukmini Dey & Sankhasubhra Nag, *An analytical study on the multi-critical behaviour and related bifurcation phenomena for relativistic black hole accretion,* General Relativity & Gravitation (**Online First Edition**), DOI: 10.1007/s10714-012-1358-z, (2012)

3. Bożena Czerny, Pawel Lachowicz, MichałDovčiak, Vladimír Karas, Thomas Pecháček & Tapas Kumar Das, *QPO in RE J1034+396: model constraints from observed trends,* Journal of Physics (JPCS), (**to appear**), arXiv:1202.2087v1 [astro-ph.CO], (2012)

4. Tapas Kumar Das, *Accreting Astrophysical Black Holes are Natural Examples of Classical Analogue Model,* Proceedings of the Twelfth Marcel Grossmann Meeting on General Relativity, edited by Thibault Damour, Robert T. Jantzen and Remo Ruffini. ISBN 978-981-4374-51-4. Singapore: World Scientific **p. 1189**, (2012)

5. Hung-Yi Pu, Ishita Maity, Tapas Kumar Das & Hsiang-Kuang Chang, *On Spin Dependence of Relativistic Acoustic Geometry,* Classical and Quantum Gravity (**under review**), arXiv:1204.1347v1 [gr-qc], (2012)

6. Neven Bilič, Arpita Choudhary, Tapas Kumar Das & Sankhasubhra Nag, *The role of axisymmetric flow configuration in the estimation of the analogue surface gravity and related Hawking like temperature,* Journal of Cosmology & Astroparticle Physics (**under review**), arXiv:1205.5506v1 [gr-qc], (2012)

7. Bożena Czerny, Vladimír Karas, Devaky Kunneriath & Tapas Kumar Das, *Mini-spiral as source of material for Sgr A* in bright state,* Astronomy & Astrophysics (**under review**), Preprint: available at http://www.hri.res.in/∼tapas/devaki.pdf/, (2012)

8. Paramita Barai, Sourav Bhattacharaya, Bożena Czerny, Tapas Kumar Das, Swathi Hegde, Ishita Maity, Sankhasubhra Nag, Tapan Naskar & Paul J Wiita. *Behaviour of low angular momentum relativistic accretion close to the event horizon,* (In Preparation), (2012)

Conference/Workshops Attended:

1. *Recent Aspects of Gravitation and Cosmology*, organized by the Relativity and Cosmology research Centre, Department of Physics, Jadavpur UniversityIndia, March, 2012

Visits to other Institutes:

1. Centre for Relativity and Cosmology, Jadavpur University, Jadavpur, India, April, 2011.
2. S. N. Bose National Centre for Basic Sciences, Kolkata, India, April, 2011.
3. Indian Association for the cultivation of sciences, Jadavpur, India, April, 2011.
4. Argelander-Institut für Astronomie, Universität Bonn, Germany, July, 2011.
5. Max Planck Institute Für Radioastronomie, Bonn, Germany, July, 2011.
6. Astronomical Institute of the Academy of Sciences, Prague, Czech Republic, July, 2011.
7. Marian Smoluchowski Institute of Physics. Jagiellonian University, Cracow, Poland, August, 2011.
8. Polish Academy of Science, N. Copernicus Astronomical centre, Warsaw, Poland, July - September, 2011.
9. One year visit at the Theoretical Physics Group of S N Bose National Centre for Basic Sciences, Kolkata India, as a Sabbatical Visiting Professor, from December 2011 to December 2012.

Invited Lectures/Seminars:

1. *Emergent Gravity as Analogue Model*, Colloquium, Centre for Relativity and Cosmology, Jadavpur University, Jadavour, Kolkata, India, April, 2011.

2. *Portrait of a Dark Face*, Colloquium, S. N. Bose National Centre for Basic Sciences, Kolkata, India, April, 2011.

3. *Black Holes at Your Bathtub*, Colloquium, S. N. Bose National Centre for Basic Sciences, Kolkata, India, April, 2011.

4. *Portrait of a Dark Face*, Colloquium, Indian Association for the cultivation of sciences, Kolkata, India, April, 2011.

5. *Black Hole Shadow Imaging*, Colloquium jointly organized by, Argelander-Institut für Astronomie, Universität Bonn, and Max Planck Institute Für Radioastronomie, Bonn, Germany, July, 2011.

6. *Analogue gravity phenomena in astrophysics*, seminar jointly organized by, Argelander-Institut für Astronomie, Universität Bonn, and Max Planck Institute Für Radioastronomie, Bonn, Germany, July, 2011.

7. *Event horizon imaging for multi-transonic flow*, Colloquium, Astronomical Institute of the Academy of Sciences, Prague, Czech Republic, July, 2011.

8. *Black hole shadow imaging for relativistic shocked accretion*, Colloquium, Marian Smoluchowski Institute of Physics, Jagiellonian University, Cracow, Poland,, August, 2011.

9. *Portrait of a dark face*, Colloquium, N. Copernicus Astronomical Centre, Warsaw, Poland, September, 2011.

10. *Axisymmetric black hole accretion as dynamical systems: An overview*, Invited Review Talk, at the workshop 'Recent Aspects of Gravitation and Cosmology', Jadavpur, Kolkata, India. March, 2012.

Other Activities:

1. **Editorial Responsibilities**

   (a) Served as the editor of the Journal of Astronomy and Space Sciences, an international journal in astronomy published by the Korean Space Science Society.

2. **Student Supervision**

   (a) MS. Arpita Choudhary from Lucknow University. Communicated a paper based on her work with me.

   (b) MS. Ishita Maity from Pune University. Communicated a paper based on her work with me.

3. **Administrative responsibilities**

   (a) Served as a member of the medical advisory committee.

   (b) Served as a member of the security advisory committee.

AseshKrishna Datta

Research Summary:

The sector comprised of scalar top and bottom quarks of the proposed Supersymmetric scenarios enjoys a special status because the dominant role it plays in the dynamics of electroweak symmetry breaking in such scenarios. They are required to be somewhat light and expected to be very much within the reach of the Large Hadron Collider (LHC) now operating at CERN, Switzerland, Geneva. We exploited a novel correlation between these members of the scalar sector which has its origin in the (electroweak) symmetry (and its subsequent breaking) the left-handed ones possess. We discuss the implications of such a correlation for the chiral-mixings that are present in these sectors and its phenomenology at the LHC. This work is done with S.Niyogi and has been circulated as a preprint.

We have been working on the implementation of the so-called Minimal Universal Extra Diemnsion (mUED) model in a massively used particle-physics event generator like Pythia. The current public implementation has been found to be not free from some major issues and is also incomplete on different grounds. Improving the implementation is key to correct simulation of this scenario at the LHC and thus turns out to be a very useful and timely work. This work is in progress with K. Matchev.

Studies are also being carried out in search for novel and more physical approaches to hadronic jet-definition and jet-algorithms which play crucial roles at the LHC. This work is in progress with K. Matchev.
Studies have been initiated to understand the role of boundary-localised terms in the scenarios with Universal Extra Dimensions and their implications for the LHC. Such a scenario can be termed as a *non-minimal* UED (nmUED) in contrast to the popular (and well-studied) mUED scenario which has such terms assumed to be vanishing at a suitable high scale (the cut-off scale of the effective field-theoretic description). This would be the first such work in this area which takes one beyond a very minimal and constrained set-up of mUED. This would potentially open up different interesting possibilities which are expected to have implications for the LHC. This work is in progress with K.Nishiwaki and S. Niyogi.

Preprints:

1. AseshKrishna Datta and Saurabh Niyogi, *Entangled System of Squarks from the Third Generation at the Large Hadron Collider.,* arXiv:1111.0200 [hep-ph]

Conference/Workshops Attended:

1. Participated in the international workshop *Physics at TeV Colliders* at Les Houches, France; June, 2011.

Visits to other Institutes:

1. Visited IACS, Kolkata; May-June, 2011.
2. Visited CERN, Geneva, Switzerland; May-June, 2011.
3. On a Sabbatical to Institute for Fundamental Theory, Department of Physics, University of Florida, Gainesville, Florida, USA; November, 2011 - March, 2012.

Other Activities:

1. Supervising a graduate student to his Ph.D. degree.
2. Serving as a member of the Computer Committee and the Library Committee.
3. Served as referees for Physical Review D and Journal of High Energy Physics (JHEP).
4. Relenting after unsuccessfully fighting out (virtually alone, for last few years) an unrelenting series of what could be called unfortunate, 'idiosyncratic' and discriminatory administrative decisions noting that such pattern of functioning of offices is unbecoming to an institute like HRI.
5. Resigned (on definitive ground) from the position of Technical Coordinator of the Regional Centre for Accelerator-based Particle Physics (RECAPP) funded by DAE.
6. Resigned (on definitive ground) as a member of the committee serving the High Performance Scientific Computing at HRI funded by DAE.

Aditi Sen De

Research Summary:

In the year 2011-2012, we have found a connection between a century-old law in mathematics, known as Benford's law, and quantum phase transitions in many-body physics. Benford's law states that the first significant digit appearing in a data would be nonuniformly distributed, with the number one appearing with the highest frequency. It had already been noted that the law holds for data ranging from infectious disease cases to national greenhouse gas emissions. We showed that Benford's law can detect quantum phase transitions, in a way that is very similar to how it has been recently used to detect earthquakes. Therefore, being certainly of very different physical origins, seismic activity and quantum cooperative phenomena may be detected by similar methods. The result has immediate implications in precise measurements in experiments in general, and for realizable quantum computers in particular. It shows that estimation of the first significant digit of measured physical observables is enough to detect the presence of quantum phase transitions in macroscopic systems.

We have also investigated the behavior of genuine multiparticle entanglement measures in different spin systems which include disordered ones. We have introduced an analytical iterative method, the density matrix recursion method, to generate arbitrary reduced density matrices, and bipartite as well as multipartite entanglement, of multi-legged periodic spin-1/2 quantum Heisenberg ladders with an arbitrary number of legs. We apply this technique to distinguish between even- and odd-legged ladders. We have also shown the emergence of opposite statistical mechanical behaviors of the two major paradigms in which quantum correlation measures are defined, viz., the entanglement-separability paradigm and the information-theoretic one.

Locally accessible information is a useful information-theoretic physical quantity of an ensemble of multiparty quantum states. We have found that it has properties akin to quantum as well as classical correlations of single multiparty quantum states. It satisfies monotonicity under local quantum operations and classical communication. However we showed that it does not follow monogamy, an important property usually satisfied by quantum correlations, and actually violates any such relation to the maximal extent. We have therefore introduced the concept of monogamy to information-theoretic quantum correlation quantities. Another information-theoretic quantity to which we have applied the concept of monogamy, is

the quantum discord, and have shown that it violates monogamy in general. We went on to show that while three-qubit generalized Greenberger-Horne-Zeilinger states follow the monogamy of quantum discord, generalized W states do not.

Publications:

1. S. Braungardt, M. Rodríguez, A. Sen(De), U. Sen, and M. Lewenstein, *Atom Counting in Expanding Ultracold Clouds*, Phys. Rev. A **84**, 043635 (2011).

2. A. Sen(De) and U. Sen, *Benford's Law Detects Quantum Phase Transitions similarly as Earthquakes*, Europhys. Lett. **95**, 50008 (2011).

3. A. Sen(De) and U. Sen, *Simulating Quantum Dynamics with Entanglement Mean Field Theory*

   J. Phys.: Conf. Ser. **297**, 012018 (2011).

4. H.S. Dhar and A. Sen (De), *Geometry versus Entanglement in Resonating Valence Bond Liquids*,

   J. Phys. A: Math. Theor. **44**, 465302 (2011).

5. R. Prabhu, S. Pradhan, A. Sen(De), and U. Sen, *Disorder overtakes Order in Information Concentration over Quantum Networks*, Phys. Rev. A **84**, 042334 (2011).

Preprints:

1. A. Sen(De) and U. Sen, *Locally Accessible Information of Multisite Quantum Ensembles Violates Monogamy,*arXiv:1108.2420

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

   arXiv:1108.5168

3. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Light Cone-Like Behavior of Quantum Monogamy Deficit and Multisite Entanglement,* arXiv:1109.4318

4. H.S. Dhar, A. Sen(De), and U. Sen, *Density Matrix Recursion Method: Genuine Multisite Entanglement Distinguishes Odd from Even Quantum Heisenberg Ladders,* arXiv:1110.3646

5. R. Prabhu, A. Sen(De), and U. Sen, *Dual quantum correlation paradigms exhibit opposite statistical mechanical properties,* arXiv:1112.1856

6. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Exclusion Principle for Quantum Dense Coding,* arXiv:1203.4114

Conference/Workshops Attended:

1. *ISCQI- International School and Conference on Quantum Information*, India, December 2011.

2. *Workshop of Quantum Discord*, Singapore, January 2012.

3. *International Worshop on Quantum Information*, India, February 2012.

Visits to other Institutes:

1. Indian Institute of Science, Bangalore, India, September 2011.

2. Centre for Quantum Technology, Singapore, January 2012.

Invited Lectures/Seminars:

1. *Interplay of Classical and Quantum Correlations in Many Body Systems*, IISc, Bangalore, September 2011.

2. *Classical And Quantum Correlations In Many Body Systems*, ISCQI-2011, IOP, Bhubaneswar, December 2011.

3. *Interplay of Classical and Quantum Correlations in Many Body Systems*, Workshop on Quantum Discord CQIT, Singapore, January 2012.

Other Activities:

1. Taught a regular course on "Quantum Information and Computation" during Aug-Dec 2011.

2. Mentored a master project of Avijit Misra.

3. Mentored two summer students, Rini Ganguly, IIT Kanpur and Pulak Banerjee, JNU, New Delhi.

4. Organized the "International Workshop on Quantum Information (IWQI-2012)" held at HRI in February 2012, with 92 speakers and participants. The

   other organizers were Manabendra Nath Bera, Anindya Biswas, Prabhu R., Arun K. Pati and Ujjwal Sen of HRI.

5. Served as a convener of the Auditorium Committee, and members of the Graduate Committee and Women Grievances Cell.

6. Served as referees in national and international journals.

Raj Gandhi

Research Summary:

The recent 5.2-sigma discovery of nonzero θ_{13} by the Daya Bay experiment, and the concurrent indication that θ_{13} is relatively large, significantly impacts existing experiments and the planning of future detectors. In many scenarios, the nonzero value of θ_{13} implies that $\theta_{23}$is likely to be different from $\pi/4$. Additionally, since $\theta_{13}$is not tiny, large detectors will be sensitive to matter effects on the oscillations of atmospheric neutrinos. This renders them capable of addressing, without assistance from beam experiments, the nature of the neutrino mass hierarchy and the octant of θ_{23}. We have recently shown that a 50 kT Liquid Argon atmospheric neutrino detector can determine both the hierarchy and the octant with high significance in moderate exposure times.

In the context of GUT baryogenesis models, it was pointed out by Nanopoulos and Weinberg that CPT conservation and the unitarity of S-matrix ensures that the net CP-violation generated in the decay of a heavy particle by graphs to first order in baryon number (B) violation is zero. We revisited this theorem (which holds for lepton number (L) violation as well) by systematically expanding the S-matrix order by order in B/L-violating couplings and find a re-formulation wherein certain consistent schemes of B/L assignment lead to the presence of both B/L conserving and B/Lviolating decay modes of a heavy particle. In such schemes, the net CP-violation is shown to be non-zero even with graphs to first order in B/L violation without actually contradicting the theorem. As an application of this result, we constructed a model in low-scale leptogenesis.

The down-going atmospheric muon neutrino and antineutrino fluxes can be significantly altered due to the presence of eV^2-scale active-sterile oscillations. We studied the sensitivity of a large magnetized iron detector like the proposed ICAL at INO to these oscillations. Such oscillations are indicated in the antineutrino sector by recent results from MiniBooNE, and by earlier ones from LSND. In addition, there are other tentative indications of the presence of sterile states in both the neutrino and antineutrino sectors. Using the allowed sterile parameter ranges in a 3+1 mixing framework in order to test the these results, we first perform a fit with active-sterile oscillations in the muon antineutrino sector only, using the ratio of downgoing muon neutrino and antineutrino events, and present the oscillation exclusion limits obtained. We then assume active-sterile oscillations in both the muon neutrino and antineutrino sectors, and compute

oscillation exclusion limits and regions of sterile parameter sensitivity using atmospheric down-going muon neutrino and anti-neutrino events independently. We find that (for both muon neutrinos and antineutrinos), even for moderate exposures (250 kT-yr) an ICAL-like detector provides significant sensitivity to regions of parameter space with $\Delta m^2 \leq 1eV^2$ and $sin^2 2\Theta_\mu\mu \geq 0.4$ where currently no bounds exist for muon antineutrinos, in addition to providing complementary coverage for the region $\Delta m^2 \geq 1eV^2$. These regions become significantly enhanced for higher exposures of about 1 Mt-yr.

We revisited the signatures of the Glashow resonance process $\bar{\nu}_e e \to W$ in the high-energy astrophysical neutrino observatory IceCube. We note that in addition to the standard hadronic and electromagnetic showers produced by an incoming neutrino at the resonance energy of $E_\nu \approx 6.3$ PeV, there are two clear signals of the process: the "pure muon" from $\bar{\nu}_e e \to \bar{\nu}_\mu \mu$ and the "contained lollipop" from $\bar{\nu}_e e \to \bar{\nu}_\tau \tau$. The event rate and the signal-to-background ratio (the ratio of the resonant to concurrent non-resonant processes) are calculated for each type of interaction, based on current flux limits on the diffuse neutrino flux. Because of the low background in the neighborhood of the resonance, the observation of only one pure muon or contained lollipop event essentially signals discovery of the resonance, even if the expected event numbers are small. We also evaluate the total event rates of the Glashow resonance from the extra-galactic diffuse neutrino flux and emphasize its utility as a discovery tool to enable first observations of such a flux. We find that one can expect 3.6 (0.65) events per year for a pure pp ($p\gamma$) source, along with an added contribution of 0.51 (0.21) from non-resonant events. We also give results as a function of the ratio of pp vs $p\gamma$ sources.

Publications and Preprints:

1. A. Bhattacharya, R. Gandhi, W. Rodejohann and A. Watanabe, *The Glashow resonance at IceCube: signatures, event rates and pp vs. $p\gamma$ interactions* JCAP **1110**, 017 (2011) [arXiv:1108.3163 [astro-ph.HE]].

2. J. L. Hewett *et al.*, *Fundamental Physics at the Intensity Frontier,'* arXiv:1205.2671 [hep-ex].

3. K. N. Abazaijan *et al.*, *Light Sterile Neutrinos: A White Paper* arXiv:1204.5379 [hep-ph].

4. V. Barger, R. Gandhi, P. Ghoshal, S. Goswami, D. Marfatia, S. Prakash,

S. K. Raut and S U. Sankar, *Neutrino mass hierarchy and octant determination with atmospheric neutrinos* arXiv:1203.6012 [hep-ph].

5. S. Choubey *et al.*, *International Design Study for the Neutrino Factory: First Progress Report* IDS-NF-017.

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

7. R. Gandhi and P. Ghoshal, *Atmospheric neutrinos as a probe of eV^2-scale active-sterile oscillations,* arXiv:1108.4360 [hep-ph].

Conference/Workshops Attended:

1. *International Workshop on Cosmic Rays and Cosmic Neutrinos: 'Looking At the Neutrino Sky'*, Italy, .June, 2011

2. *Sterile Neutrinos at the Cross-roads*, USA, September 2011.

3. *Fundamental Physics at the Intensity Frontier*, USA, December 2011.

Visits to other Institutes:

1. University of Wisconsin, Madison, USA, May 2011,

2. CERN Theory Division, Geneva, Switzerland, June/July 2011.

Invited Lectures/Seminars:

1. *Ultra-High Energy Neutrinos and the Glashow resonance*, Plenary talk , International Workshop on Cosmic Rays and Cosmic Neutrinos, "Looking at the Neutrino Sky", ICTP, Trieste, June 2011.

2. *Atmospheric Neutrinos as a probe of the sterile sector*, Plenary talk, Sterile Neutrinos at the Cross-roads, Virginia Tech, VA, September 2011

3. *The Physics Potential of INO*, Invited talk, Physics at the Intensity Frontier, Washington DC, November 2011

Other Activities:

1. I am a member of the Program Management Committee of the Indian Neutrino Observatory.

2. I am the Co-ordinator for the Neutrino Physics Working Group of the Indo-US Project X Collaboration.

3. I am a member of the Indo-US Science and Technolgy Foundation sponsored Indo-US Joint Centre on 'Physics beyond Standard Model'-JC/23-2010, Supported under the IUSSTF Award.

4. I am currently guiding 3 students towards their Ph.D and also have been guiding several students on their graduate projects each semester. In addition, I am on several institute committees.

Rajesh Gopakumar

Research Summary:

In the last year my investigations have been largely on the duality between the higher spin gravity theories on AdS_3 and solvable CFTs in two dimensions. This is an interesting case of the AdS/CFT correspondence involving nonsupersymmetric quantum field theories and can potentially teach us more about this correspondence in a new setting. With M. Gaberdiel, T. Hartman and S. Raju we compared the partition function of the 2d CFTs in the large N 'tHooft like limit with the one loop gravitational partition function and found a matching of the perturbative spectra. However, there were light (but non-perturbative) states whose role in the duality was not completely clear. In work with A. Castro, M. Gutperle and J. Raeymakers we showed that there is a class of solutions (conical defects) in the bulk higher spin theory which can be identified with the light states under an appropriate analytic continuation of parameters.

With Gaberdiel we also clarified the nature of the symmetry algebra on the bulk side and the nontrivial matching with the higher spin symmetry of the 2d CFT. The important observation is that the bulk classical symmetry algebra is deformed at the quantum level in a very nontrivial way. The deformation is such that a nonperturbative truncation of the theory to finite W_N symmetry is possible. This is due to a nontrivial triality of equivalences within the algebra. After identifying the quantum symmetry algebra, we could track representations of the algebra including those corresponding to the light states which led to a precise formulation of the analytic continuation given earlier. This also led to a modification of the conjectured equivalence whereby one of the earlier perturbative scalars is now viewed more naturally as a non-perturbative scalar.

In another line of investigation with A. Hashimoto, I. Klebanov, S. Sachdev and K. Schoutens we studied more general 2d coset conformal field theories which also possess a higher spin symmetry, as possible analogues of "strange" metals in one spatial dimension. The preliminary results on scaling dimensions of various operators makes this an interesting candidate for a nontrivial generalization of the Luttinger liquids in one dimension. We are currently studying the possible large AdS_3 dual which might well be a string theory with unbroken higher spin symmetry. With my student Roji Pius, I have also been following up on the earlier investigation on the "simplest gauge-string duality". We have computed general correlation functions in the simple Gaussian matrix model and compared

with the proposed topological string dual and the preliminary results are encouraging.

Publications:

1. M. R. Gaberdiel, R. Gopakumar, T. Hartman and S. Raju, *Partition Functions of Holographic Minimal Models* JHEP **1108**, 077, (2011).

2. A. Castro, R. Gopakumar, M. Gutperle and J. Raeymakers, *Conical Defects in Higher spin Theories* JHEP **1202**, 096, (2012).

Preprints:

1. M. Gaberdiel and R. Gopakumar, *Triality in Minimal Model Holography*, arXiv:1205.2472 [hep-th].

2. R. Gopakumar, A. Hashimoto, I. Klebanov, S. Sachdev and K. Schoutens, *Strange Metals in One Spatial Dimension*, (To Appear)

Conference/Workshops Attended:

1. *RADCOR School*, SINP, Kolkata, Apr. 2011.

2. *Great Lakes Meeting*, Univ. of Chicago, Chicago, USA, Apr. 2011.

3. *Kavli Indo-US Frontiers of Science Meeting*, National Academy of Sciences(USA), Irvine, USA, Apr. 2011.

4. *School on Applied AdS/CFT*, Isfahan, Iran, May. 2011.

5. *Solvay Workshop on Gauge Theories, Strings and Geometry*, Brussels, May 2011.

6. *Strings 2011*, Stockholm, Sweden, Jun. 2011.

7. *Benasque workshop on String Theory*, Benasque, Spain, Jul. 2011.

8. *KIAS-YITP Workshop on String Theory, Holography and Beyond*, Seoul, Sep. 2011.

9. *XVII European Workshop on String Theory*, Padova, Italy, Oct. 2011.

10. *HRI Workshop on Higher Spin Theories and Holography*, HRI, Nov. 2011.

11. *National Strings Meeting*, Delhi University, New Delhi, Dec. 2011

12. *ICTS Meeting on Random Matrix Theory and its Applications*, ICTS, Bangalore (Jan. 2012)

13. *CERN Winter School on Supergravity, Strings and Gauge Theories*, CERN, Geneva, Feb. 2012.

Visits to other Institutes:

1. KITP, Santa Barbara, USA, Apr. 2011.

2. IAS, Princeton, USA, Apr. 2011.

3. Simons Centre for Geometry and Physics, Stony Brook, USA, Apr. 2011.

4. DESY, Hamburg, May 2011.

5. ICTS-TIFR, Bangalore, Jun., 2011.

6. KIAS, Seoul, Sep. 2011.

7. CERN, Geneva, Feb. 2012.

8. Instt. for Geometry and Applications, Univ. of Adelaide, Australia, Mar. 2012.

Invited Lectures/Seminars:

1. *Scattering Amplitudes and AdS/CFT* (two lectures), RADCOR School, SINP, Kolkata Apr. 2011.

2. *A Large N Dual to 2d CFTs*, Great Lakes Meeting, Univ. of Chicago, USA, Apr. 2011.

3. *A Large N Dual to 2d CFTs*, KITP Seminar, Santa Barbara, Apr. 2011.

4. *What is the Simplest Gauge-String Duality*, String Theory Seminar, Simons Centre for Geometry and Physics, Stony Brook, Apr. 2011.

5. *Higher Spins and Holography*,(three lectures) School on Applied AdS/CFT, Isfahan, May. 2011.

6. *A Large N Dual to 2d CFTs* Solvay Workshop, Brussels, May 2011.

7. *A Large N Dual to 2d CFTs*, Theory Seminar, DESY, Hamburg, May. 2011.

8. *Minimal Model Holography*, Strings 2011, Uppsala, Sweden, Jun. 2011.

9. *Minimal Model Holography*, Benasque Workshop, Benasque, Spain, Jul. 2011.

10. *Higher Spins and Holography*, KIAS-YITP Workshop on String Theory, Seoul, Sep. 2011.

11. *Higher Spins and Holography*, (Plenary Review Talk), XVII European Workshop on String Theory, Padova, Italy, Oct. 2011.

12. *Higher Spins and Holography*, (Plenary Review Talk) National Strings Meeting Delhi University, Dec. 2011.

13. *Higher Spin Theories and Holography*, (four lectures), CERN Winter School on Supergravity, Strings and Gauge Theories, CERN Geneva, Feb. 2012.

14. *Mathematical Implications of Gauge-String Dualities*, (five lectures) IGA Lecture Series, Univ. of Adelaide, Mar. 2011.

15. *String Theory and the Quest for Quantum Spacetime* (colloquium) Dept. of Mathematics, Univ. of Adelaide, Mar. 2011.

Academic recognition/Awards:

- IGA Distinguished Lecturer at the Institute of Geometry and Applications (IGA), Univ. of Adelaide.
- Invited to deliver A. K. Raychaudhuri Memorial Lecture, IACS Kolkata.

Other Activities:

1. Member, Organising Committee, Indo-US Frontiers of Science Meeting, Irvine, USA, 2011.

2. Member, Organising Committee, ICTS Meeting on Random Matrix Theory and Applications, IISc. Bangalore, (Jan. 2012).

3. Member, Organising Committee, 4th Asian Winter School on String Theory, Particle Physics and Cosmology, Tohuku, Japan (Jan. 2012).

4. Member, Commission on Mathematical Physics, IUPAP, (2012-).

5. Member, External Review Committee, Physics Dept., NISER Bhubaneshwar, Feb. 2011.

6. Member, National Committee for SERC schools in HEP, (2011-).

7. Co-Organiser, HRI Workshop on Higher Spin Theories and Holography, HRI, Nov. 2011.

8. Co-Organiser, ICTS Discussion Meeting on String Theory, Bangalore, Jun. 2012.

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

Dileep Jatkar

Research Summary:

In last one year, I have worked on three different topics. One of them is continuation of my work on dyon counting formula in $N = 4$ supersymmetric four dimensional string theories. I also worked on decay of massive scalar field in de Sitter spacetime as well as studied various boundary conditions for $SU(2)$ gauge fields in four dimensional anti-de Sitter space.

Publications:

1. *BKM superalgebras from counting dyons in N=4 supersymmetric type II compactifications*, S. Govindarajan, D. P. Jatkar and K. Gopala Krishna, Nucl. Phys. B **859**, 143 (2012) [arXiv:1106.1318].

2. *On the Decay of Massive Fields in de Sitter*, D. P. Jatkar, L. Leblond and A. Rajaraman, Phys. Rev. D **85**, 024047 (2012) [arXiv:1107.3513 [hep-th]].

Preprints:

1. *Boundary conditions for SU(2) Yang-Mills on* AdS_4, D. P. Jatkar and J. -H. Oh, arXiv:1203.2106 [hep-th].

Conference/Workshops Attended:

1. Indian String Meeting at New Delhi, December 6-13 2011.

Visits to other Institutes:

1. Indian Institute of Technology Madras, Chennai (May 15-26, 2011).

2. Institute of Mathematical Sciences, Chennai (May 27-31, 2011).

3. Indian Instutute of Science, Bangalore (June 19-30, 2011).

4. National Institute for Science Education and Research, Bhubaneswar (October 12-24, 2011).

Pinaki Majumdar

Research Summary:

With my students I have continued work on correlated systems, sometimes involving disorder, by employing a new formulation. This involves rewriting the many body interaction in terms of auxiliary variables, making a classical approximation on them, and solving the resulting problem via a real space Monte Carlo. This reproduces many of the earlier results in the field, and allows access to spectral and spatial features hitherto out of reach.

Publications:

1. Viveka Nand Singh and Pinaki Majumdar, *Antiferromagnetic order and Phase Coexistence in a Model of Antisite Disordered Double Perovskites,* Eur Phys. J. B **83**, 147, (2011)

2. T. Archer, C. D. Pemmaraju, S. Sanvito, C. Franchini, J. He, A. Filippetti, P. Delugas, D. Puggioni, V. Fiorentini, R. Tiwari, and P. Majumdar, *Exchange interactions and magnetic phases of transition metal oxides: Benchmarking advanced ab initio methods,* Phys. Rev. B **84**, 115114, (2011)

Preprints:

1. Viveka Nand Singh, and Pinaki Majumdar, *Huge Positive Magnetoresistance in Antiferromagnetic Double Perovskite Metals,* arXiv:1107.0782

2. Subrat Kumar Das, Viveka Nand Singh, and Pinaki Majumdar, *The Magnon Spectrum in the Domain Ferromagnetic State of Antisite Disordered Double Perovskites,* arXiv:1204.1194

3. Rajarshi Tiwari and Pinaki Majumdar, *Visualising the Mott Transition*, (in preparation).

4. Sabyasachi Tarat and Pinaki Majumdar, *Pairing Fluctuations, the BCS-BEC Crossover and Strong Disorder in Superconductors*, (in preparation).

Conference/Workshops Attended:

1. *ICTS Conference on Correlated Systems*, IISc Bangalore, Dec 2011.
2. *ATHENA School and Conference*, SNBNCBS Kolkata, March 2012.
3. *Indo-UK Seminar or Correlated Oxides*, Cambridge UK, March 2012.

Invited Lectures/Seminars:

1. *Visualising Many Body Physics*, Coochbehar Lecture, IACS Kolkata, Feb 2012.

Other Activities:

1. Coordinated an International School on Functional Materials at HRI during March-April 2011.
2. Served in the KVPY interviews at HRI, Jan 2012.
3. Led an Indian team to Cambridge University for an Indo-UK Meeting on Oxides, March 2012.

Biswarup Mukhopadhyaya

Research Summary:

Results coming in from the Large Hadron Collider (LHC) were analysed in the light of various kinds of physics beyond the standard model. The data in the jets + missing transverse energy hannel were used to derive important constrants on supersymmetry (SUSY) with light third family.
(N. Desai, B. Mukhopadhyaya)

The possibility of the Higgs boson in SUSY decaying invisibly was examined in the light of the LHC data on the $\gamma\gamma$ and ZZ final states. The possibility of a non-negligible branching fraction for a Higgs boson decaying invisibly, in a way consistent with the observed data in the above channel, was pointed out.
(N. Desai, B. Mukhopadhyaya, S. Niyogi)

The potential for probing a class of new physics at the LHC using same-sign trilepton and four-lepton signals was explored in detail, as part on an ongoing study. The usefulness of using such signals in probing the dynamics underlying new physics was pointed out.
(S. Mukhopadhyay and B. Mukhopadhyaya)

Some distinctive siugnatures of non-universal Higgs masses in SUSY were explored in the context of the LHC. In particular, criteria were set down, whereby one could observe sigantures of specific polarisation states of tau-leptons, and obtain therefrom information about the particle spectrum of theoretical scdenario under question.
(S. Bhattacharya, S. Biswas, B. Mukhopadhyaya, M. Nojiri)

Possible CP-violating coupling between a Higgs boson and two gauge bosons was studied in the context of the LHC. New kinematical criteria for accentuating the non-strandard interactions, their CP-violating nature, and absorptive [parts in the relevant transition amplitudes, were derived.
(N. Desai, D. K. Ghosh, B. Mukhopadhyaya)

The collider signature of a model of scalar dark matter was investigated. The scenario, entailing the presence of pseudo-Majorons interacting with the standard model Higgs, was found to be accessible by the LHC data.
(K. Ghosh, B. Mukhopadhyaya, U. Sarkar)

The implications of a randam-Sundrum warped geometry with two warpoed compact spacelike extra dimensions were examined. The massive graviton states in such a scenario were found to display a clustering pattern, whose observation through resonances in TeV-scale experiments could

be rather spectacular.
(B. Mukhopadhyaya, S. Sen, S. SenGupta)

The possible astronomical signal of a decaying axino dark matter in SUSY with R-parity violation was investigated in the cintext of the Chandra telescope. The regions of the parameter space that could be probed from the X-ray observation of different galaxies.
(P. Dey, B. Mukhopadhyaya, S. Roy, S. Vempati)

Publications:

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

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

3. Satyanarayan Mukhopadhyay, Biswarup Mukhopadhyaya, *Same-sign trileptons at the LHC: A Window to lepton-number violating supersymmetry,* Phys. Rev. **D84**, 095001, (2011)

4. Kirtiman Ghosh, Biswarup Mukhopadhyaya, Utpal Sarkar, *Signals of an invisibly decaying Higgs in a scalar dark matter scenario: a study for the Large Hadron Collider,* Phys. Rev. **D84**, 015017, (2011)

5. Subhaditya Bhattacharya, Sanjoy Biswas, Biswarup Mukhopadhyaya, Mihoko M. Nojiri, *Signatures of supersymmetry with non-universal Higgs mass at the Large Hadron Collider,* JHEP **1202**, 104, (2012)

6. Nishita Desai, Dilip Kumar Ghosh, Biswarup Mukhopadhyaya, *CP-violating HWW couplings at the Large Hadron Collider,* Phys. Rev. **D83**, 113004, (2011)

Preprints:

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

2. Nishita Desai, Biswarup Mukhopadhyaya, Saurabh Niyogi, *Constraints on invisible Higgs decay in MSSM in the light of diphoton rates from the LHC,* arXiv:1202.5190[hep-ph]

3. Biswarup Mukhopadhyaya, Somasri Sen, Soumitra SenGupta, *Matter-gravity interaction in a multiply warped braneworld,* arXiv:1106.1027[hep-ph]

Conference/Workshops Attended:

1. *Planck and the LHC*, Pune, India, August, 2011
2. *ATLAS Collaboration meeting on SUSY*, Geneva, Switzerland, October, 2011
3. *Think tank on Physics at the LHC*, Sariska, India, December, 2011
4. *National Conference on Advances in Physics*, Roorkee, India, February, 2012
5. *B-physics at the LHC*, Kolkata, India, February, 2011
6. *Symposium on recent trends in High Energy Physics*, Kolkata, India, March, 2012

Visits to other Institutes:

1. Indian Association for the Cultivation of Science, Kolkata, India, June, 2011.
2. IUCAA, Pune, India, August, 2011.
3. CERN, Geneva, Switzerland, October, 2011.
4. LAPTH, Annecy, France, October, 2011.
5. University of Vienna, Austria, November, 2011.
6. IIT, Roorkee, India, February, 2012.
7. Physical Research Laboratory, Ahmedabad, India, March, 2012.
8. University of Calcutta, India, March, 2012.

Invited Lectures/Seminars:

1. *Looking into the heart of matter*, Keynote Address at C. K. Majumdar memorial Workshop, S. N. Bose National Centre for Basic Sciences, Kolkata, June, 2011.

2. *LHC, dark matter, the visible and the invisible*, Planck and the LHC, IUCAA, Pune, August, 2011.

3. *The world of the very small*, Invited lecture, SGTB Khalsa College, Delhi, August, 2011.

4. *Same-sign trileptons at the LHC*, Invited Talk at ATLAS meeting on supersymmetry, CERN, Geneva, Switzerland, October, 2011. August, 2011.

5. *New physics with low missing energy: identification and model discrimination at the LHC*, Invited seminar, LAPTH, ANNECY, France, October, 2011.

6. *New physics with low missing energy: identification and model discrimination at the LHC*, Invited seminar, University of Vienna, Austria, November, 2011.

7. *Probing the structure of the universe*, Physics Society Inauguration lecture, University of Allahabad, November, 2011.

8. *What is everything made of?*, Invited talk at UGC-sponsored programme, Kalna College, West Bengal, November, 2011.

9. *The wonder that is the Higgs boson*, Invited talk at National Conference on Advances in Physics, IIT, Roorkee, February, 2012. *All about the Higgs*, One day symposium on recent trends in High Energy Physics, University of Calcutta, March, 2012.

Other Activities:

1. Co-ordinator, regional centre for Accelerator-based Partricle Physics.

2. Member, Physics Graduate Committee, HRI, —August, 2011.

3. Member, Faculty Advisory Committee, HRI.

4. Member, Medical Advisory Committee, HRI.

5. Member, Computer Committee, HRI, August, 2011 –.

Satchidanand Naik

Research Summary:

Wilson loop in $\mathcal{N}$ = 1 SUSY and QCD Confinement
The Confinement in Yang-Mills theory remains yet a challenging problem. The mechanism initially proposed by Nambu- Mandelstam and 't Hooft is due to the dual Meissner effect which is still obscure to prove. There is a remarkable progress in the mid 90's by Seiberg and Witten– Who proposedWilson loop in $\mathcal{N}$ = 1 SUSY and QCD Confinement that monopoles of $\mathcal{N}$ =2 SUSY Yang-Mills theory condense to form a chromoelectric flux tubes which may be realised as confinement of coloured quarks.Infact in the Seiberg-Witten mechanism $\mathcal{N}$ = 2 SUSY SU(N) gauge theory is brken to $U(1)^{N-1}$ due to adjoint Higgs getting mass and the monopoles are formed in the Coulomb phase and a softly SUSY breaking mass term is added and confinement occurs when monopole becomes massless. This is entirely in broken abelian symmetric theory.On the contrary QCD confinement is in the symmetric phase where there is no Higgs. This suggests to explore perhaps $\mathcal{N}$ = 1 SUSY theory which may be a closer kin of QCD. Here we use Holographic principle to extract the vacuum expectation value of the Non-BPS Wilson loop as close as to its exact value.

Preprint:

1. Author: Satchidananda Naik, *Closed String Field Theory for Super Twistors and Maximal Supergravity ,* Progress of Theoretical Physics Supplement No 188 page 126 (2011)

Workshops Attended:

- **Indian String Meeting 2011, Delhi University,from 7th Dec-13th Dec 2011**

Visits to other Institutes:

- **Delhi University,from 7th-13th dec,2011**

Invited Lectures/Seminars:

Wilson loop in $\mathcal{N}$ = 1 SUSY and QCD Confinement ,
at NSM 11 ,Delhi University

Courses Given:

1. **Advanced quantum field theory**

G. Venketeswara Pai

Research Summary:

My research focuses on two class of problems that include some aspects of manganite physics and spin polarized transport in mesoscale systems. The substitution of oxygen isotope in doped manganites is known to give rise to unexpected features such as driving a metal-insulator transition and dramatically reducing the ferromagnetic Curie temperature. Using a two-fluid model, and incorporating hybridization between itinerant and localized electrons, we study this problem using a modified coherent potential approximation (CPA) that takes into account the renormalization of Jahn-Teller energy and resultant mixing of both electronic states in a self-consistent way. Another problem involves the study of spin wave excitations in A-type metallic manganites and the magnon induced orbital fluctuations that can arise in such systems. Parallely, we have also been working on the anisotropic magnetic phases and effect of Coulomb interaction on the nanoscale phase separation in these systems using the two fluid model based on an exact diagonalization based Monte Carlo approach. The second set of problems involves strategies to develop pure spin currents using mesoscopic quantum wire networks by tuning Aharanov-Bohm flux threading them, intrinsic Dresselhaus spin-orbit (SO) coupling, and Rashaba SO interaction arising due to gate voltage and we plan to extend it to look at the effect of disorder and time varying fields.

Recently, I have started working on a Ginzburg-Landau theory for cuprates that treats both superconductivity and antiferromagnetism and magnetic properties of junctions of topological insulators.

Preprints:

1. *Isotope Effect in Doped Manganites*
   with Saurabh Pradhan
   (in preparation)

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

Other Activities:

1. Guided a VSP project student, Shatabdi Chakrabarty (BHU-Varanasi) during June-July 2011.

2. Guided the project of a third year student, Nyayabanta Swain, during Jan-May 2012.

3. Guided the project of a first year student, Ajanta Maity, during Jan-May 2012.

4. Taught a second year graduate course, Condensed Matter Physics II, during Aug-Dec 2011.

5. Taught a first year graduate course, Statistical Mechanics, during Jan-May 2012.

6. Organized a workshop on "Low Dimensional Quantum Systems" at HRI during 10-13 Oct, 2011.

7. Convener of the Library committee and member of the Physics PDF-Visitors' committee, Auditorium Committee, and the DAE Laison (Academic and Plan) Committee.

Sudhakar Panda

Research Summary:

We studied the observational constraints for the axionic quintessence model in string theory, constructed earlier by us. It is found that the evolution of the universe is sensitive to the initial value of the axion field. Thus the initial value of the axion field controls the deviation of the evolution from that of cosmological constant model of dark energy. We used Supernova Type Ia dataset, the data from BAO measurements, WMAP measurement of the shift parameter and the H(z) measurements. We find the reconstructed equation of state of the axion field has small deviation from $\omega = -1$.

We computed the Post-Newtonian parameter for scaler- tensor gravity theory when the acion functional for the scaler field is a non- standard one, namely the Dirac-Born-Infeld type action proposed by me and my collaborators for the tachyon field living on a non-BPS brane. we investigated both linear and conformal couplings when the scaler field is non-minimally coupled to gravity via the scaler curvature. We found that the PPN parameter becomes a function of the effective mass of the scaler field. Using this PPN parameter we estimated the time delay for a signal to travel the round trip distance between a ground antenna and a reflector placed in a spacecraft which is produced due to the gravitational field of the sun. Our result was compared with the results obtained by the Cassini mission to derive the constraints on the model parameters.

We investigated the motion of a test particle in higher dimensions due to the presence of extended sources like Dp-branes by studying the motion in the transverse space of the brane. This is contrasted with the motion of a point particle in the Schwarzschild background in higher dimensions. Since Dp-branes are specific to 10-dimensional space time and exact solutions of geodesic equations for this particular space time has not been possible so far for the Schwarzschild background, our focus here is to find the leading order solution of the geodesic equation (for motion of light rays). This enables us to compute the bending of light in both the backgrounds. We showed that contrary to the well known result of no noncircular bound orbits for a massive particle, in Schwarzschild background, for $d \geq 5$, the Dp-brane background does allow bound elliptic motion only for $p = 6$ and the perihelion of the ellipse regresses instead of advancing. We also found that circular orbits for photon are allowed only for $p \leq 3$.

Publications:

1. A.Ali, A. Deshamukhya, S. Panda and M. Sami. *Inflation with improved D3-brane potential and the fine tuning associated with the model,* Eur. Phys.J. C71 (2011) 1672.

2. R. Andringa, E. Bergshoeff, S. Panda and M. de Roo, *Newtonian Gravity and the Bargman Algebra,* Class.Quant.Grav. 28 (2011) 105011.

3. S. Panda, Y. Sumitomo and S. P. Trivedi, *Axions as Quintessence in String Theory,* Phys.Rev.D83 (2011) 083506.

4. N. Chandachani Devi, S. Panda and A.A. Sen, *Solar System Constraints on Scalar Tensor Theories with Non-Standard Action,* Phys.Rev.D84 (2011) 063521.

5. G.Gupta, S. Panda and A.A. Sen, *Observational Constraints on Axions as Quintessence in String Theory,* Phys. Rev. D85 (2012) 023501.

Preprints:

1. A. Bhattacharjee, A. Das, L. Greenwood and S. Panda, *Motion of a test particle in the transverse space of Dp-branes,* arXiv:1112.0887 [hep-th].

Conference/Workshops Attended:

1. *NSM-2011*, Delhi University India, December, 2011.

2. *Indo-UK Workshop on Comology*, IUCAA,India, August 2011.

3. *WHEPP-XII*. Mahabaleswar, India, January 2012.

Visits to other Institutes:

1. University of Groningen, Groningen, The Netherlands, September 2011,

2. Assam University, Silchar, India, February, 2012,

3. University of Canterbury, Christchurch, New Zealanad, April, 2011.

Invited Lectures/Seminars:

1. *Brane Inflation and Reheating*, Indo-UK Meeting on Cosmology, IUCAA, Pune, Pune, August 2011.
2. *Bergmann algebra and Newtonian gravity*,NSM, Delhi University, Delhi, December 2011.
3. *Inflation and Quitessence in String Theory*, WHEPP-XII, Mahabaleshwar, January 2012 .
4. *Axionic Quintessence in String Theory*, Groningen University Netherlands, September 2011.
5. *Inflation and Quitessence in String Theory*, Erskine Lecture, University of Canterbury, Christchurch, April 2011.

Other Activities:

1. Dean, Administration, from May, 2009.
2. Convener, Local Works Committee, from August, 2011.
3. Member, Faculty Advisory Committee, from August, 2011.
4. Member, Monitoring Committee for Construction work in HRI, 2011-12.
5. Member, Board of Studies, CTP, Jamia Univ, Delhi. 2011.
6. Organizer, NSM Meeting, December 2011.
7. Organizer, ISM Meeting, to be held in December 2012.
8. Referee of Research articles for JHEP, JCAP and Phys. Rev. D , 2011-12.

Arun Kumar Pati

Research Summary:

My research area broadly spans quantum information and quantum computation. During the academic year 2011-2012, I have mostly worked in topics related to quantum correlations in multiparticle systems, trying to understand monogamy of quantum correlations, relating quantum correlation measures to quantum entanglement measures in multisite systems and advocating an exclusion principle for quantum dense coding which may find important practical application in future quantum communications. In addition, we have also worked on implication of existence of nonlocal super-correlations in the presence of closed tme-like curves. We have also introduced the notion of locally unextendible non-maximally entangled basis and applied this to super dense coding.

It is known that there exist non-local correlations that respect no-signaling criterion, but violate Bell-type inequalities more than quantum-mechanical correlations. Such super quantum correlations were introduced as the Popescu-Rohrlich (PR) box. We have considered such non-local boxes with two (three) inputs and two (three) outputs. We show that these super quantum correlations can lead to signaling when at least one of the input bit has access to a word line along a closed time-like curve.

In another work, we have introduced the concept of the locally unextendible non-maximally entangled basis (LUNMEB) in $H^d \bigotimes H^d$. It is shown that such a basis consists of d orthogonal vectors for a non-maximally entangled state. However, there can be a maximum of $(d-1)^2$ orthogonal vectors for non-maximally entangled state if it is maximally entangled in $(d-1)$ dimensional subspace. Such a basis plays an important role in determining the number of classical bits that one can send in a superdense coding protocol using a non-maximally entangled state as a resource. By constructing appropriate POVM operators, we find that the number of classical bits one can transmit using a non-maximally entangled state as a resource is $(1+p_0\frac{d}{d-1})\log d$, where p_0 is the smallest Schmidt coefficient. However, when the state is maximally entangled in its subspace then one can send up to $2\log(d-1)$ bits. We also find that for $d=3$, former may be more suitable for the superdense coding.

For last several years, there has been a growing interest in trying to understand quantum correlations that goes beyond quantum entanglement. Usually, quantum correlations are expected to respect all the conditions required for them to be good measures of quantumness in the bipartite

scenario. In a multipartite setting, sharing entanglement between several parties is restricted by the monogamy of entanglement. In this work, we take over the concept of monogamy to an information-theoretic quantum correlation measure, and find that it violates monogamy in general. Using the notion of interaction information, we identify necessary and sufficient conditions for the quantum discord to obey monogamy. We show that while three-qubit generalized Greenberger-Horne-Zeilinger states follow monogamy, generalized W states do not. Thus, our work suggets that monogamy of quantum discord can be used to detect two inequivalent classes of three qubit states.

Current investigations have revealed that there are two important paradigms for defining quantum correlations in quantum information theory. One is using the notion of information-theoretic measure and the other one is the notion of entanglement. We find an analytical relation between two measures of quantum correlations, one in each paradigm, and show that only a certain cone-like region on the two-dimensional space spanned by these measures is accessible to pure three-qubit states. The information-theoretic multiparty quantum correlation measure is related to the monogamy considerations of a bipartite information-theoretic quantum correlation measure, while the entanglement-separability multiparty measure is the generalized geometric measure, a genuine multiparty entanglement measure. We also find an analytical relation between two multiparty entanglement measures, and again obtain a cone-like accessible region in this case. One of the multisite measures in this case is related to the monogamy of a bipartite entanglement measure, while the other is again the generalized geometric measure. Just like in relativity, events cannot occur outside the space-time light cone, we analogously find here that state points corresponding to pure three-qubit states cannot fall outside the two-dimensional cone-like structure between quantum monogamy scores and a genuine multisite entanglement measure.

In another work, we have shown that the classical capacity of quantum states, as quantified by its ability to perform dense coding, respects an exclusion principle, for arbitrary pure or mixed three-party states in any dimension. This states that no two bipartite states which are reduced states of a common tripartite quantum state can have simultaneous quantum advantage in dense coding. The exclusion principle is robust against noise. Such principle also holds for arbitrary number of parties. This exclusion principle is independent of the content and distribution of entanglement in the multipartite state. We also find a strict monogamy relation for multiport classical capacities of multi-party quantum states in arbitrary dimen-

sions. In the scenario of two senders and a single receiver, we show that if two of them wish to send classical information to a single receiver independently, then the corresponding dense coding capacities satisfy the monogamy relation, similar to the one for quantum correlations.

Publications:

1. Arun K. Pati, Indranil Chakrabarty, and Pankaj Agrawal,
   Purification of mixed states with closed timelike curve is not possible
   Phys. Rev. A **84**, 062325 (2011).

2. Indranil Chakrabarty, Pankaj Agrawal, Arun K Pati,
   Locally Unextendible Non-Maximally Entangled Basis
   Quantum Information and Computation, **12**, 0271 (2012).

3. R. Prabhu, Arun Kumar Pati, Aditi Sen(De), and Ujjwal Sen,
   Conditions for monogamy of quantum correlations: Greenberger-Horne-Zeilinger versus W states,
   Phys. Rev. A **85**, 040102(R) (2012).

4. Arun Kumar Pati, Biswajit Pradhan and Pankaj Agrawal,
   Entangled brachistochrone: minimum time to reach the target entangled state,
   Quantum Information Processing, **11**, 841 (2012).

5. I. Chakrabarty, T. Pramanik, A. K. Pati, P. Agrawal,
   CTC assisted PR box type correlation can lead to signaling,
   arXiv:1107.2908 (2011)

6. R. Prabhu, Arun Kumar Pati, Aditi Sen De, Ujjwal Sen,
   Light Cone-Like Behavior of Quantum Monogamy Score and Multisite Entanglement,
   arXiv:1109.4318 (2011).

7. R. Prabhu, Arun Kumar Pati, Aditi Sen De, Ujjwal Sen,
   Exclusion Principle for Quantum Dense Coding,
   arXiv:1203.4114 (2012)

Chair person and Conference/Workshops organized:

1. Organizing committee of International Conference on Quantum Optics and Quantum Computing (ICQOQC)-2011 at held at JIIT, Noida during Mrch 24th-26th, 2011.

2. Program Commitee Member of 11th Asian Quantum Information Science (AQIS) Conference held during August 23 - 30, 2011, at KIAS Korea.

3. Organizer of School and Conference on Quantum Information (SQI and CQI- 2011) held at IOP, Bhubaneswar, India during December 13-17 and 18-22nd, 2011.

4. General Chair of International Conference on Nano-Science, Technology and Societal Implication (NSTSI11), held at C V Raman College of Engineering, Bhubaneswar during December 8th-10th. 2011.

5. Organizer of International Workshop on Quantum Information (IWQI)-2012 held at HRI, Allahabad during Feb 20-26th, 2012.

Invited Lectures/Seminars:

1. *Invited as a Mentor*, DST Inspire Program, Pandit Ravishankar University, Raipur, June, 2011.

Academic recognition:

- Invited to join as Editor-in-Chief of Journal of Quantum Information Science (JQIS).

Other Activities:

1. **Editorial Activities:**

   (i) Guest Editor of a Special Issue for Quantum Information Processing (2012) Springer, Vol 11.

   (ii) Editorial board member of Journal ISRN Mathematical Physics (2011)

2. **Project Evaluation:** Expert member of DST project proposals in the area of Quantum Information and Quantum Theory.

3. **Student Supervision**

(i) Guided two summer visiting students selected through Indian Academy of Science and two through HRI vsp program.

(ii) This year guided 5 students from Predoc program at HRI in the area of Quantum Information theory and general quantum theory.

(iii) Guiding two students S. Bagchi and A. Mishra for their Ph. D. program.

4. **Administrative responsibilities**

   (a) Member of the Medical committee.
   (b) Member of the Housing committee.
   (c) Member of Visitor and PDF committee.
   (d) Member of Guest House and Pantry committee.

Media Report:

1. Interview featured in Times of India, Bangalore, Jan (2012).
   $(http://www.hri.res.in/ \sim akpati/akptimes\_2012.pdf)$

Sumathi Rao

Research Summary:

During the period, April 2011-March 2012, I worked in the areas of topological insulators and non-abelian anyons. In the last few years, there has been a paradigm shift in condensed matter physics, where instead of classifying states of matter by studying the symmetries of the free energy, there has been a move towards a topological classification of the states of matter, where Hamiltonians whose variations do not close a bulk gap are considered to be in the same topological class. Thus topological order parameters and topological field theories have gained in importance in the last few years. On the other hand, non-abelian braid statistics and non-abelian anyons have also gained in importance in the last few years, particularly because of the possibility of applications in the field of quantum computing. The two fields are related because topological states with ground state degeneracies lead to excitations with non-abelian statistics.

More specifically, we have studied the Fabry-Perot type resonances which appear in the transport characteristics of a helical edge state exposed to a uniform magnetic field over a finite length. The intrinsic spin anisotropy of the edge state allows us to tune the resonances as a function of the direction of the magnetic field keeping its magnitude fixed. These resonances provide a unique way of identifying the helical nature of the edge states.

I have also been studying the corner states that appear at the corner of a topological insulator. Although edge states of topological insulators have been studied in great detail, the peculiarities that appear at a corner due to the boundary effects on the spin polarisation of the edge states have not been investigated and this is the focus of my interest.

Finally, most recently, I have also been studying non-abelian braid group statistics and non-abelian anyons in the context of its recent resurgence in the field of quantum computation.

Preprints in progress:

1. Amit Agrawal, Sourin Das and Sumathi Rao, *Magnetic field induced Fabry-Perot resonances in helical edge states*, cond-mat/1112.5400

2. Sumathi Rao, *Transport through bent helical edge states of a quantum spin Hall system* , (in preparation)

Conferences/Workshops attended:

1. Workshop on women in science, United States Embassy and the Dept of Science and Technology, New Delhi, Sep 12, 2011
2. Workshop on low dimensional quantum systems, HRI, Allahabad, 10-13 October, 2011
3. The international conference on physics of novel and emerging materials, IACS, Kolkata, Nov 15- 17, 2011
4. American Physical Society, March meeting, Boston, U.S.A., Feb 27 - March 2, 2012
5. K. S. Krishnan Discussion meeting on Frontiers in Quantum Science 2012, IMSc, Chennai, March 19-21, 2012

Visits to other Institutes:

1. Dept of Physics, Delhi University, Sep 13-14 , 2011
2. Institute of Physics, Bhubaneswar, Sept 26-28, 2011
3. Indian Institute of Technology, Kanpur, Nov 7-8, 2011

Invited Lectures/Seminars:

1. *Topological insulators and helical edge states*, Institute of Physics, Bhubaneswar, Sept 26, 2011
2. *Topological insulators and helical edge states*, Workshop on low dimensional quantum systems, HRI, Allahabad, October 10, 2011
3. *Topological insulators and helical edge states*, Dept of physics, IIT, Kanpur, Nov 8, 2011
4. *Topological insulators and helical edge states*, International conference on physics of novel and emerging materials, IACS, Kolkata, Nov 17, 2011
5. *Spin-polarized multi-terminal transport in helical edge states*, March meeting, Boston, U.S.A, 29 Feb, 2012

Other Activities:

1. Acting director (*Director-in-charge*), May 2011 - May 2012
2. Member, Board of Studies, School of Physics, Jawaharlal Nehru University, New Delhi
3. Member, Academic council, IIIT, Allahabad

V. Ravindran

Research Summary:

My recent research works involve the detailed study on physics beyond the standard model signals at the hadron colliders, taking into account higher order QCD radiative corrections. I have studied how to discriminate the spin-2 Randall-Sundrum graviton excitation against the hypothesis of a spin-0 exchange giving the same number of events under the peak, by means of the angular analysis applied to resonant diphoton events expected to be observed at the LHC. In the models with large extra-dimensions, I have examined the production of a vector boson (γ/Z) in association with the Kaluza-Klein (KK) modes of the graviton via gluon fusion. I have calculated the next to next to leading order QCD corrections to the resonant production of sneutrino and charged slepton at the Tevatron and the Large Hadron Collider within the context of R-parity violating supersymmetric model and demonstrated the role of NNLO QCD corrections in reducing uncertainties resulting from renormalisation and factorisation scales and thereby making our predictions reliable.

Currently, I have been studying the prospects of probing large extra dimension model at the LHC through neutral triple gauge boson production processes. I have considered $\gamma\gamma\gamma, \gamma\gamma Z, \gamma ZZ$ and ZZZ production processes, and already presented the leading order results for various kinematic distributions at the LHC for $\sqrt{S} = 14TeV$. In this study, I have found that the results are sensitive to factorisation and renormalisation scales. The scale dependence can be reduced by incorporating the next to leading order QCD corrections. This computation involves technically complicated issues, namely computation of phase space integrals involving 4 particles in the final state for the real emission processes and of pentagon loop diagrams in the virtual QCD corrections. These can be achieved by semi-analytical methods. Along with my student, I have been testing these methods for the known processes namely di-photon production and Drell-Yan production at next to leading order level.

Publications:

1. M.C. Kumar, Prakash Mathews, A.A. Pankov, N. Paver, V. Ravindran, A.V. Tsytrinov, *Spin-analysis of s-channel diphoton resonances at the LHC*. Phys.Rev. D84,115008 (2011)

2. Ambresh Shivaji, V. Ravindran, Pankaj Agrawal, *Production of a KK-*

graviton and a Vector Boson in ADD Model via Gluon fusion. JHEP 1202,057 (2012)

3. M.C. Kumar, Prakash Mathews, V. Ravindran, Satyajit Seth, *Neutral triple electroweak gauge boson production in the large extra-dimension model at the LHC.* ,Phys.Rev. D85,094507 (2012)

   Swapan K. Majhi, Prakash Mathews, V. Ravindran. *$O(\alpha_s^2)$ QCD corrections to the resonant sneutrino / slepton production at LHC.* Accepted in Nuclear Physics B.

Conference/Workshops Attended:

1. *Radiative Corrections for the LHC: 2. Radcor 2011 Symposium* , Mamallapuram, India , September 2011.

2. *Think Tank on Physics@LHC: Monte Carlo Event Generators at NLO and Jet Physics*, Sariska Palace, Rajasthan, India, December 2011.

Visits to other Institutes:

1. Saha Institute Of Nuclear Physics, Kolkata, India, March 2012.

Invited Lectures/Seminars:

1. *Radiative Corrections for the LHC: 1. Advanced School* Order α_s QCD radiative corrections to scalar particle production at Hadron Colliders Saha Institute of Nuclear Physics, Kolkata, 04 - 11 April, 2011.

Academic recognition/Awards:

- Elected during 2012: Fellow of the Indian Academy of Sciences.

Other Activities:

1. I have given two courses for graduate students at HRI: 1) Mathematical Methods-2,(Aug-Dec 2011), 2) Quantum Field Theory-1 (Jan-May 2012)

2. I have worked for Medical and Housing committees.

Ashoke Sen

Research Summary:

During the period April 2011 - March 2012 I continued to explore various aspects of black hole entropy. Along with my collaborators I computed logarithmic corrections to entropy of supersymmetric black holes in many 4 and 5 dimensional theories. Wherever the microscopic results are available our results turn out to be in perfect agreement with the microscopic results, providing us with a consistency test of string theory. On the other hand our analysis also makes new predictions for logarithmic corrections to the black hole entropy in theories where microscopic results are not available.
Another topic I worked on is wall crossing formula. I proved the equivalence of a formula derived in collaboration with Manschot and Pioline earlier and the Konsevich-Soibelman wall crossing formula. I also used the wall crossing formula to determine the complete spectrum of BPS states in N=4 supersymmetric Yang-Mills theories.
I also analyzed the spectrum of negative discriminant states in N=4 supersymmetric string theories and showed the consistency between the microscopic results and the results from the black hole side.

Publications:

1. A. Sen, "BPS Spectrum, Indices and Wall Crossing in N=4 Supersymmetric Yang-Mills Theories," arXiv:1203.4889 [hep-th].

2. A. Sen, "Equivalence of Three Wall Crossing Formulae," arXiv:1112.2515 [hep-th].

3. A. Sen, "Logarithmic Corrections to Rotating Extremal Black Hole Entropy in Four and Five Dimensions," arXiv:1109.3706 [hep-th].

4. A. Sen, "Logarithmic Corrections to N=2 Black Hole Entropy: An Infrared Window into the Microstates," arXiv:1108.3842 [hep-th].

5. S. Banerjee, R. K. Gupta, I. Mandal and A. Sen, "Logarithmic Corrections to N=4 and N=8 Black Hole Entropy: A One Loop Test of Quantum Gravity," JHEP **1111** (2011) 143 [arXiv:1106.0080 [hep-th]].

6. A. Sen, "Negative discriminant states in N=4 supersymmetric string theories," JHEP **1110** (2011) 073 [arXiv:1104.1498 [hep-th]].

Invited Lectures/Seminars at Schools/Conferences:

1. Sixth regional meeting in string theory, Milos, Greece, June 2011
2. Strings 2011, Uppsala, June/July 2011.
3. National Strings meeting, University of Delhi, December 2011.
4. Asian Winter School, Kusatsu, Japan, January, 2012
5. Indo-Israeli meeting, Jerusalem, February 2012.
6. ASICTP spring school, Trieste, Italy, March 2012
7. N=4 Super Yang-Mills Theory, 35 Years After, Caltech, Pasadena, March 2012.

Courses given at HRI

1. Quantum mechanics 1, August-December, 2011
2. Quantum mechanics 2, January-May, 2011

Prasenjit Sen

Research Summary:

Major research activities during the year electronic structure calculations of atomic clusters, superatoms, two-dimensional materials, and bulk oxides. In atomic clusters, electronic structure calculations for neutral and anionic Rh_n clusters were performed using density functional theory (DFT) methods. The goal was to understand and explain the photoelectron spectroscopy experimental results from Prof. Kit Bowen's group. We performed similar calculations on 3d transition metal doped calcium clusters, and identified $FeCa_8$ as a new magnetic superatom.

Hybrid 2D hexagonal $(BN)_xC_y$ sheets have recently been synthesized which has generated renewed interest in this material. The advantage is that the energy gap can be tuned by changing the composition. Adsorption of metal atoms will be important in any application these materials are put into. Motivated by this we studied adsorption and diffusion of transition metal atoms Fe, Co and Ni on a BNC_2 sheet through DFT methods.
A new class materials called spin gapless semiconductors were predicted recently. $PbPdO_2$ was given as an example of this based on DFT calculations with the local density approximation (LDA). The important and useful aspect of a spin gapless semiconductor is that the electronic excitations are exactly gapless in one spin channel, while they are gapped pin the other. It is well known that LDA does not produce band gaps correctly. Therefore, predicting a new class of materials based on a single LDA calculation is questionable. Through a set of more refined DFT calculations beyond LDA we argued that it is premature to call $PbPdO_2$ a spin gapless semiconductor.

Publications:

1. V. M. Medel, J. U. Reveles, S. N. Khanna, V. Chauhan, P. Sen and A. W. Castleman, *Hunds rule in superatoms with transition metal impurities,* Proc. Nat. Acad. Sc., USA **100**, 10062, (2011)

2. P. Srivastava, M. Deshpande and P. Sen, *First-principles study of electronic and magnetic properties of transition metal adsorbed h-BNC2 sheets,* Phys. Chem. Chem. Phys. **13**, 21593, (2011)

3. V. Chauhan, V. Medel, J. U. Reveles, S. N. Khanna and P. Sen, *Shell magnetism in transition metal doped calcium superatom,* Chem. Phys. Lett. **528**, 39, (2012)

Preprints:

1. P. Srivastava, B. J. Nagare, D. G. Kanhere and P. Sen, *Predicting spin-gapless semiconductors: The case of $PbPdO_2$,* (submitted)

2. H. Wang, Y. J. Ko, K. Bowen, M. Beltran, F. Buendia, V. Chauhan and P. Sen, *Electronic, magnetic and structural properties of Rn (n=1-9) clusters: Joint negative ion photoelectron and density ab initio studies,* (in preparation)

Conference/Workshops Attended:

1. *ACCMS-6*, Singapore, September, 2011.

Visits to other Institutes:

1. Rajasthan Central University, Kishangarh, India, January, 2012.

Other Activities:

1. Reviewed manuscripts for the journals Physical Chemistry Chemical Physics and Applied Physics Letters.

2. Acted as the nodal person at HRI for the Garuda Grid throughout the year.

3. Taught a course on Atomic and Molecular Physics.

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

5. Organized an *International Symposium on Clusters, Cluster Assemblies and Nano-scale Materials* (ISCANM-II) in November, 2011.

Ujjwal Sen

Research Summary:

During the past year, my main research interests have been to study quantum information properties of multiparty quantum states, and also to use quantum information techniques in states of quantum many-body systems.

Quantum correlations of many-particle systems tend to be monogamous in nature, and we have tried to look into the monogamy properties of quantum information-theoretic quantities like locally accessible information, quantum discord, and capacity of quantum dense coding. In particular, we found that locally accessible information of ensembles of multiparty quantum systems is a physical quantity, which has correlation properties that are akin to classical as well as quantum correlations.

We have used a multisite genuine quantum entanglement measure, called 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 have termed it as "Density Matrix Recursion Method", to analytically calculate multisite entanglement properties of quantum Heisenberg ladders. Other works include a study of the atom-counting properties of an expanding ultracold cloud during a superfluid-insulator transition.

Publications:

1. S. Braungardt, M. Rodríguez, A. Sen(De), U. Sen, and M. Lewenstein, *Atom Counting in Expanding Ultracold Clouds*, Phys. Rev. A **84**, 043635 (2011).

2. A. Sen(De) and U. Sen, *Benford's Law Detects Quantum Phase Transitions similarly as Earthquakes*, Europhys. Lett. **95**, 50008 (2011).

3. A. Sen(De) and U. Sen, *Simulating Quantum Dynamics with Entanglement Mean Field Theory* J. Phys.: Conf. Ser. **297**, 012018 (2011).

4. R. Prabhu, S. Pradhan, A. Sen(De), and U. Sen, *Disorder overtakes Order in Information Concentration over Quantum Networks*, Phys. Rev. A **84**, 042334 (2011).

Preprints:

1. A. Sen(De) and U. Sen, *Locally Accessible Information of Multisite Quantum Ensembles Violates Monogamy,* arXiv:1108.2420

2. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Conditions for Monogamy of Quantum Discord: Monogamous Greenberger-Horne-Zeilinger versus Polygamous W states,* arXiv:1108.5168

3. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Light Cone-Like Behavior of Quantum Monogamy Score and Multisite Entanglement,* arXiv:1109.4318

4. H.S. Dhar, A. Sen(De), and U. Sen, *Density Matrix Recursion Method: Genuine Multisite Entanglement Distinguishes Odd from Even Quantum Heisenberg Ladders,* arXiv:1110.3646

5. R. Prabhu, A. Sen(De), and U. Sen, *Dual quantum correlation paradigms exhibit opposite statistical mechanical properties,* arXiv:1112.1856

6. R. Prabhu, A.K. Pati, A. Sen(De), and U. Sen, *Exclusion Principle for Quantum Dense Coding,* arXiv:1203.4114

Conference/Workshops Attended:

1. *ISCQI- International School and Conference on Quantum Information*, India, December 2011.

2. *Workshop of Quantum Discord*, Singapore, January 2012.

3. *International Worshop on Quantum Information*, India, February 2012.

Invited Lectures/Seminars:

1. Presented a seminar on *"Benford's Law: Detection of Quantum Phase Transitions Similar to Earthquakes"* at IISc, Bengaluru, September 2011.

2. Presented a series of two school talks on *"Quantum correlations in many-body systems"*, in ISCQI-2011, at IOP, Bhubaneswar, December 2011. [pdf available on program website.]

3. Presented an invited talk on *"Benford's Law Detects Quantum Phase Transitions Similarly As Earthquakes"*, in ISCQI-2011, at IOP, Bhubaneswar, December 2011. [pdf available on program website.]

4. Presented an invited talk on *"Quantum discord heralds entanglement revival in many-body systems and detects multisite entanglement classes"*, in the Workshop on Quantum Discord, at CQT, NUS, Singapore, January 2012.

Visits to other Institutes:

1. Indian Institute of Science, Bengaluru, India, September 2011.
2. Centre for Quantum Technologies, Singapore, January 2012.
3. Indian Association for the Cultivation of Science, Kolkata, December 2011.

Other Activities:

1. Taught a one-semester course on "Numerical methods" during Jan-May 2012.
2. Helped in conducting the "Talent Search Examinations" (physics part) for students of classes IX-X and classes XI-XII of schools in Allahabad.
3. Guided projects, during Jan-May 2012, of the following HRI graduate students.
   (a) Samrat Kadge and Dibyakanti Mukherjee, on "Local hidden variables and bound entanglement",
   (b) Taushif Ahmed, on "Classical correlations in the transverse XY model",
   (c) Aritra Gupta, on "Generating Gaussian-distributed random numbers",
   (d) Abhishek Joshi, on "Improper integrals",
   (e) Avijit Misra, on "Quantum discord in the transverse XY model",
   (f) Utkarsh Mishra, on "Cloning a linearly independent set of states", and
   (g) Roji Pius, on "Benford's law".
4. Organized the "International Workshop on Quantum Information (IWQI-2012)" held at HRI in February 2012, with 92 speakers and participants. The other organizers were Manabendra Nath Bera, Anindya Biswas, Prabhu R., Arun K. Pati and Aditi Sen(De), of HRI. [www.hri.res.in/~iwqi12/]

5. Guided the project work of a student, Sudipto Singha Roy of IIT Bombay, Mumbai, under the visiting students programme (VSP) of HRI during May-July 2011.

6. Served as the convenor of the Computer Committee, and members of HBNI Cell, Talent Search Committee, and the Cluster Computing Committee at HRI.

7. Served/Serving as coordinators of the DAE projects to the QIC group within the XI and XII plans.

8. Served as referees in national and international journals.

9. Served as a member of the PhD committee of Vivekanand Singh.

Ram Lal Awasthi

Research Summary:

In nonsupersymmetric (non-SUSY) SO(10) grand unification framework we explored a TeV scale inverse seesaw mechanism for neutrino masses implemented with a low-mass Z' gauge boson accessible to Large Hadron Collider. We also derived the renormalization group equations for fermion masses and mixings in the presence of the intermediate symmetries of the model and extracted the Dirac neutrino mass matrix at the TeV scale from successful GUT-scale parameterization of fermion masses. We estimated leptonic nonunitarity effects measurable at neutrino factories and lepton flavor violating decays expected to be probed in near future. Our prediction on the nonunitarity matrix element $\eta_{\mu\tau}$ for degenerate right-handed (RH) neutrinos turned out to be similar to the supersymmetric SO(10) case and we got new predictions with significantly enhanced value of its phase $\delta_{\mu\tau} \simeq 10^{-4} - 10^{-2}$ in partial degeneracy case of RH neutrino masses from naturally emerging contraint due to exprimental bounds. An important distinguishing characteristic of minimal model is two-loop prediction of the proton lifetime with maximum value $(\tau_p)_{max} = 7 \times 10^{34}$yrs accessible to ongoing search experiments for the decay $p \to e^+\pi^0$ which might testify model in near future. In such cases models with simple extensions with longer proton lifetime predictions can be the possible candidate.
At present we are looking at neutrinoless double beta decay cross section in Left-right SUSY SO(10) model in inverse seesaw scenario at TeV scale. At the begining level of results, we notice very small correction of heavy neutrino to $0\nu\beta\beta$-decay, as opposed to large contribution of TeV scale Type-I and Type-II seesaw (*Work in progress*).

Preprints:

1. Ram Lal Awasthi, Mina K. Parida (*arXiv:1112.1826*)

Conference/Workshop Attended:

1. *Nu-Horizones V*, HRI-Allahabad, India, Feb 1-3, 2012

Other Activities:

1. **Course Assistance:** *Math Methods II* Jan-April 2012

Atri Bhattacharya

Research Summary:

In the academic year 2011-12, I worked on deciphering signatures of neutrino events at the IceCube using the Glashow resonance and understanding the effect of CPT and unitarity in baryogenesis and leptogenesis.

Publications:

1. Atri Bhattacharya, Raj Gandhi, Werner Rodejohann, Atsushi Watanabe, *The Glashow resonance at IceCube: signatures, event rates and pp vs. $p\gamma$ interactions,* JCAP **1110**, 017, (2011)

Preprints:

1. Atri Bhattacharya, Raj Gandhi, Satyanarayan Mukhopadhyay, *Reanalysing the implications of CPT and unitarity for baryogenesis and leptogenesis,* arXiv:1109.1832 [hep-ph]

Conference/Workshops Attended:

1. *Nu HoRIzons V*, India, February, 2012

Invited Lectures/Seminars:

1. *The Glashow Resonance as a hint to extra-galactic neutrinos*, Nu HoRIzons V, Harish-Chandra Research Institute, Allahabad, February, 2012.

Vikas Chauhan

Research Summary:

We have done first-principle study on TM doped alkaline earth metal clusters. We identify $FeCa_8$ as magnetic superatom. Superatoms are clusters of atoms characterized by electronic and chemical properties that are approximate to that of an atom in the periodic table from electronic and chemical point of view. Al_{13} is one of the famous example known as superhalogen. Besides the stablity due to crystal field effect in $FeCa_8$ cluster, it has $4\mu_B$ magnetic moment due exchange effects in supershells. When we carry our calcualtion in TM doped Strontium cluster, we have not found any cluster in $TMSr_8$ series which fullfill the criteria for superatom. Interestingly we find $CrSr_9$ another candidate for magnetic superatom for which again crystal field and exchange effect were crucial. Besides this study we have done therotical calculation for TM doped aluminium cluster in which $CoAl_3$ and $FeAl_4$ are found to be stable cluster. However stability of these cluster can not be explained in terms of shell model.

Publications:

1. Victor M. Medel, Jose Ulises Reveles, Shiv N. Khanna, Vikas Chauhan, Prasenjit Sen, and A.Welford Castleman, *Hund's rule in Superatoms with transition metal impurities,* PNAS **Vol. 108**,10062,(2011)

2. Vikas Chauhan, Victor M. Medel, Jose Ulises Reveles, Shiv N. Khanna, Prasenjit Sen, *Shell magnetism in transition metal doped calcium superatom,* CPL **Vol. 528**,39,(2012)

Conference/Workshops Attended:

1. *International Symposium on clusters, clusters assemblies and Nanoscales materials-II at H.R.I.*, India, 28 Nov 2011 - 01 Dec 2011

2. *Unifying Concepts in Materials, JA Krumhansl School and Symposium 2012 at JNCASR, Bangalore* , India.

Other Activities:

1. As tutor for Condensed matter physics, Jan to May, 2012.

Ujjal Kumar Dey

Research Summary:

During this academic year I have worked on the Universal Extra Dimensional (UED) models. Generally in these type of models a discrete symmetry (Z_2-symmetry) ensures the stability of the lightest Kaluza-Klein particle (LKP) which can be a viable dark matter candidate. Kinetic terms, when taken asymmetrically, on the fixed points of the orbifold breaks the above mentioned symmetry and LKP is no longer a stable particle. Normally the first Kaluza-Klein excitation of photon is the LKP. The single production of this first Kaluza-Klein excitation of photon and its decay to standard model fermion-antifermion pairs in the presence of these boundary localised kinetic terms is examined. It has been shown how experiments at Large Hadron Collider can constrain these types of terms for different compactification scales.

Preprints:

1. Anindya Datta, Ujjal Kumar Dey, Amitava Raychaudhuri, Avirup Shaw *Universal Extra-Dimensional models with boundary localised kinetic terms: Probing at the LHC*, arXiv:1205.4334 [hep-ph].

Conference/Workshops Attended:

1. *Leptogenesis and GUT*, University of Calcutta, Kolkata, November 23-25, 2011.

2. *NuHorizon V*, Harish-Chandra Research Institute, Allahabad, February 1-3, 2012.

3. *B Physics at the LHC*, Kolkata, March 2-4, 2012.

Other Activities:

1. Teaching assistant for General Theory of Relativity course, August-December, 2011.

Dhiraj Kumar Hazra

Research Summary:

Analysis of the scalar bi-spectrum of the primordial perturbation generated during single scalar field driven inflationary models in equilateral and general triangular configuration was carried out. The effects of features in the primordial power spectra has signatures in the bi-spectra and it has been numerically calculated in this work.

Scalar bi-spectrum during preheating has been analytically and numerially estimated. It has been shown in this work that during preheating the scalar bi-spectrum is conserved.

Estimation of the expected bounds on primordial bispectrum in the Lyman-α forest using 3D bispectrum along multiple lines of sight has been done.

Preprints:

1. D. K. Hazra, L. Sriramkumar and J. Martin, *On the discriminating power of $f_{\rm NL}$, arXiv:1201.0926 [astro-ph.CO]*

2. D. K. Hazra and T. Guha Sarkar, *Primordial Non-Gaussianity in the Forest: 3D Bispectrum of Ly-alpha Flux Spectra Along Multiple Lines of Sight , arXiv:1205.2790 [astro-ph.CO]*

3. D. K. Hazra, J. Martin and L. Sriramkumar, *The scalar bi-spectrum during preheating in single field inflationary models , arXiv:1206.0442 [astro-ph.CO]*

Conference/Workshops Attended:

1. *Indo-UK Scientific Seminar: Confronting Particle-Cosmology with Planck and LHC*, Inter-University Centre for Astronomy and Astrophysics, Pune, India, August 10–12, 2011.

2. *COSMO 11—International Conference on Particle Physics and Cosmology*, The Centro de Astrofísica da Universidade do Porto, Porto, Portugal, August 22-26, 2011.

3. *UK Particle Cosmology Network Meeting*, Institute of Cosmology and Gravitation, University of Portsmouth, Portsmouth, U.K., September 13–14, 2011.

4. *International Conference on Gravitation and Cosmology [ICGC2011]*, Goa, India, December 14–19, 2011.

Visits to other Institutes:

1. The Abdus Salam International Center for Theoretical Physics, Trieste, Italy, September, 2011

2. Royal Observatory, University of Edinburgh, Edinburgh, U.K., September, 2011

3. Department of Applied Mathematics and Theoretical Physics, University of Cambridge, University of Cambridge, U.K., September, 2011

4. AstroParticule et Cosmologie, Paris, France, September, 2011

5. Institut d'Astrophysique de Paris, Paris, France, September, 2011

6. CERN, Geneva, Switzerland, September, 2011

7. Department of Theoretical Physics, University of Geneva, Geneva, Switzerland, September, 2011

8. Tata Institute of Fundamenta Research, Mumbai, India, May, 2012

Invited Lectures/Seminars:

1. *Oscillations in the inflaton potential: Exact numerical analysis and comparison with the recent and forthcoming CMB datasets*, talks at *Indo-UK Scientific Seminar: Confronting Particle-Cosmology with Planck and LHC*, Inter-University Centre for Astronomy and Astrophysics, Pune, India, August 10–12, 2011; and *COSMO 11—International Conference on Particle Physics and Cosmology*, The Centro de Astrofísica da Universidade do Porto, Porto, Portugal, August 22-26, 2011.

2. *On the discriminating power of $f_{\rm NL}$*, talk at *UK Particle Cosmology Network Meeting*, Institute of Cosmology and Gravitation, University of Portsmouth, Portsmouth, U.K., September 13–14, 2011; International Conference on Gravitation and Cosmology [ICGC2011], Goa, India, December 14-19.

3. *Local and non-local features in the primordial power spectrum and associated non-Gaussianities*,seminars at The Abdus Salam International Center for Theoretical Physics, Trieste, Italy, September 1, 2011; Royal Observatory, University of Edinburgh, Edinburgh, U.K., September 6, 2011; Department of Applied Mathematics and Theoretical Physics, University of Cambridge, University of Cambridge, U.K., September 16, 2011; AstroParticule et Cosmologie, Paris, France, September 19, 2011; Institut d'Astrophysique de Paris, Paris, France, September 22, 2011; Cosmo Coffee, CERN, Geneva, Switzerland, September 28, 2011; Department of Theoretical Physics, University of Geneva, Geneva, Switzerland, September 29, 2011; Tata Institute of Fundamenta Research, Mumbai, India, May 10, 2012.

Shailesh Lal

Research Summary:

The AdS/CFT correspondence is a remarkable statement about the equivalence of a string theory on an AdS spacetime with a conformal field theory defined on the AdS boundary. It has perhaps been best tested in the supergravity approximation, where the gauge theory is necessarily strongly coupled. However, as a means of understanding how the duality works, it might be useful to consider the regime in the parameter space where the gauge theory is free. The bulk would then be described by the tensionless limit of string theory. This would contain an infinite number of massless interacting fields with arbitrary spin which are expected to be described by Vasiliev's Higher-Spin Theories. To probe these questions, Rajesh Gopakumar, Rajesh Kumar Gupta and I had previously obtained the heat kernel for an arbitrary-spin particle on AdS. We are currently using these results to obtain clues about how the free gauge theory sees the higher-spin symmetry in the specific context of AdS_5/CFT_4 duality. A preprint with some explorations in this direction was published.

Also, Arjun Bagchi, Arunabha Saha, Bindusar Sahoo, and I have explored the deformation of higher-spin theories in AdS_3 by a topological mass term. We were able to construct logarithmic modes at the 'chiral' point $\mu\ell = 1$ indicating a perturbative instability, and conjectured the possibility of a logarithmic CFT dual for these deformed HS theories. We also computed the one-loop partition function of the HS theory (by heat kernel methods) and found results consistent with the expectation of an LCFT dual.

Publications:

1. Arjun Bagchi, Shailesh Lal, Arunabha Saha, Bindusar Sahoo, *One loop partition function for Topologically Massive Higher Spin Gravity,* JHEP **1112**, 068, (2011),[arXiv:1107.2063]

2. Arjun Bagchi, Shailesh Lal, Arunabha Saha, Bindusar Sahoo, *Topologically Massive Higher Spin Gravity,* JHEP **1110**, 150, (2011),[arXiv:1107.0915]

Preprints:

1. Rajesh Kumar Gupta, Shailesh Lal, *Partition Functions for Higher-Spin theories in AdS* arXiv:1205.1130 [hep-th]

Conference/Workshops Attended:

1. *National Strings Meet*, Delhi, India, December 2011.

Visits to other Institutes:

1. CERN, Geneva, Switzerland, November 2011.
2. ETH, Zurich, Switzerland, November 2011.
3. University of Rome Tor Vergata, Rome, Italy, November 2011.
4. Scuola Normale Superiore, Pisa, Italy, November 2011.
5. Vienna University of Technology, Vienna, Austria, November 2011.
6. Universiteit van Amsterdam, Amsterdam, The Netherlands, November 2011.
7. ULB, Brussels, Belgium, November 2011.
8. Universiteit Utrecht, Utrecht, The Netherlands, November 2011.

Invited Lectures/Seminars:

1. *Higher-Spin Theories in Odd Dimensions*, National Strings Meet, Delhi, India, December 2011.
2. *Higher-Spin Theories in Odd Dimensions*, Universiteit Utrecht, Utrecht, The Netherlands, November 2011.
3. *Higher-Spin Theories in Odd Dimensions*, ULB, Brussels, Belgium, November 2011.
4. *Higher-Spin Theories in Odd Dimensions*, Universiteit van Amsterdam, Amsterdam, The Netherlands, November 2011.
5. *Higher-Spin Theories in Odd Dimensions*, Vienna University of Technology, Vienna, Austria, November 2011.
6. *Higher-Spin Theories in Odd Dimensions*, Scuola Normale Superiore, Pisa, Italy, November 2011.
7. *Higher-Spin Theories in Odd Dimensions*, University of Rome Tor Vergata, Rome, Italy, November 2011.

8. *Higher-Spin Theories in Odd Dimensions*, ETH, Zurich, Switzerland, November 2011.

9. *Higher-Spin Theories in Odd Dimensions*, CERN, Geneva, Switzerland, November 2011.

Manoj Kumar Mandal

Research Summary:

Currently, I have been studying physics beyond the standard model signals at the LHC taking into account the potential higher order QCD radiative corrections. It is important to incorporate these corrections as these corrections reduce various theoretical uncertainties arising from missing higher order quantum corrections through renormalisation and factorisation scales. Recently there are some works on probing large extra dimension models at the LHC through neutral triple gauge boson production processes such as $\gamma\gamma\gamma, \gamma\gamma Z, \gamma ZZ$ and ZZZ production processes, the results are being available only at the leading order level. The scale dependence in these processes can be reduced through the inclusion of the next to leading order (NLO) QCD corrections. This computation involves computation of phase space integrals involving 4 particles in the final state for the real emission processes and pentagon loop diagrams in the virtual QCD corrections. These can be done by semi-analytical methods and with my supervisor, I have been working on these methods for already reported processes namely di-photon production and Drell-Yan production at next to leading order level to study the feasibility of carrying out the computations for the three vector boson productions beyond leading order QCD. We have found that the real emission processes can be done using FKS subtraction method and the virtual corrections can be done using dimensional recurrence method.

Conference/Workshops Attended:

1. *Radiative Corrections for the LHC: 1. Advanced School*,Saha Institute of Nuclear Physics, Kolkata, April 2011

2. *CTEQ Summer School on QCD Analysis and Phenomenology* , Madison, Wisconsin USA, July 2011.

3. *Radiative Corrections for the LHC: 2. Radcor 2011 Symposium* , Mamallapuram, India, September 2011.

4. *Think Tank on Physics@LHC: Monte Carlo Event Generators at NLO and Jet Physics*, Sariska Palace, Rajasthan, India, December 2011.

Visits to other Institutes:

1. Saha Institute Of Nuclear Physics, Kolkata, India, March 2012.

Saurabh Niyogi

Research Summary:

With the hint of Higgs boson at the LHC, there are lots of activity going on in this direction. In one of my work, I have studied how elusive the Higgs could be, even with the present LHC data. We find that a large region of the MSSM parameter space can indeed yield the lightest neutral Higgs mass around 125 GeV, as suggested by the recent ATLAS data, and also lead to event rates around, or slightly higher than, the standard model expectation in the two-photon and four-lepton channels.
In another work, we study the strongly interacting sector of the Non-minimal Extra Dimensions (NMUED) with one extra spatial dimension orbifolded on S^1/Z_2 in the presence of brane-localized terms. We study the masses of the level-1 Kaluza-Klein gluon and the quarks and find the strong interaction vertices involving these particles. Cross sections for various generic final states are estimated for the Large Hadron Collider.

Preprints:

1. Nishita Desai, Biswarup Mukhopadhyaya, Saurabh Niyogi, *Constraints on invisible Higgs decay in MSSM in the light of diphoton rates from the LHC*, arXiv:1202.5190
2. AseshKrishna Datta, Kenji Nishiwaki, Saurabh Niyogi, *Non-minimal Universal Extra Dimensions: The strongly interacting sector at the Large Hadron Collider* (in preparation)

Conference/Workshops Attended:

1. *Think Tank on Physics@LHC*, Sariska, India, December 5-9, 2011
2. *WHEPP-XII*, Mahabaleshwar, India, January 9-15, 2012.

Other Activities:

1. Teaching Assistant of Quantum Field Theory Course.

Sourav Mitra

Research Summary:

Areas of research are Cosmology, structure formation in the Universe, intergalactic medium and reionization - mainly, semi-analytical modelling of cosmological reionization and comparison with observations. A brief summary of my research work is given below:

1. Reionization

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

1.1 Model-independent Constraints on Reionization

Using a semi-analytical model developed by Choudhury & Ferrara (2005, 2006), we study the observational constraints on reionization via a principal component analysis (PCA). The advantage of this approach is that it provides constraints on reionization in a model–independent manner. Assuming that reionization at $z > 6$ is primarily driven by stellar sources, we decompose the unknown function $N_{\rm ion}(z)$, representing the number of photons in the IGM per baryon in collapsed objects, into its principal components and constrain the latter using the photoionization rate, $\Gamma_{\rm PI}$, obtained from Lyα forest Gunn-Peterson optical depth, the redshift distribution of Lyman-limit systems $\mathrm{d}N_{\rm LL}/\mathrm{d}z$ at $0.36 < z < 6$ and the

angular power spectra C_l for TT, TE and EE modes which seem to contain somewhat more information than taking the electron scattering optical depth $\tau_{\rm el}$ as a single data point (Mitra, Choudhury, & Ferrara 2011). Using Markov Chain Monte Carlo methods, we find that all the quantities related to reionization can be severely constrained at $z < 6$ whereas a broad range of reionization histories at $z > 6$ are still permitted by the current data sets. With currently available data from WMAP7, we constrain $0.080 < \tau_{\rm el} < 0.112$ (95% CL) and also conclude that reionization is 50% complete between $9.0 < z(Q_{\rm HII} = 0.5) < 11.8$ (95% CL) and is 99% complete between $5.8 < z(Q_{\rm HII} = 0.99) < 10.4$ (95% CL). With the forthcoming PLANCK data on large-scale polarization (ignoring effect of foregrounds), the $z > 6$ constraints will be improved considerably, e.g., the $2-\sigma$ error on $\tau_{\rm el}$ will be reduced to 0.009 and the uncertainties on $z(Q_{\rm HII} = 0.5)$ and $z(Q_{\rm HII} = 0.99)$ would be ~ 1 and 3 (95% CL), respectively (Mitra, Choudhury, & Ferrara 2012). For more stringent constraints on reionization at $z > 6$, one has to rely on data sets other than CMB. Our method will be useful in such case since it can be used for non-parametric reconstruction of reionization history with arbitrary data sets.

1.2 Effects of Reionization on Cosmological Parameters

We perform an analysis of the recent WMAP7 data considering physically motivated and viable reionization scenarios with the aim of assessing their effects on cosmological parameter determinations. The main novelties are: (i) the combination of CMB data with astrophysical results from quasar absorption line experiments; (ii) the joint variation of both the cosmological and astrophysical (governing the evolution of the free electron fraction $x_e(z)$) parameters. Including a realistic, data-constrained reionization history in the analysis induces appreciable changes in the cosmological parameter values deduced through a standard WMAP7 analysis (Pandolfi et. al. 2011). Particularly noteworthy are the variations in $\Omega_b h^2 = 0.02258^{+0.00057}_{-0.00056}$ (WMAP7) vs. $\Omega_b h^2 = 0.02183 \pm 0.00054$ (WMAP7 + ASTRO), and the new constraints for the scalar spectral index, for which WMAP7 + ASTRO excludes the Harrison-Zel'dovich value $n_s = 1$ at $> 3\sigma$. Finally, the e.s. optical depth value is considerably decreased with respect to the standard WMAP7, i.e. $\tau_{\rm el} = 0.080 \pm 0.012$. We conclude that the inclusion of astrophysical datasets, allowing to robustly constrain the reionization history, in the extraction procedure of cosmological parameters leads to relatively important differences in the final determination of their values.

2. Neutral Hydrogen at High Redshifts

Perhaps the most promising prospect of detecting the fluctuations in the neutral hydrogen (HI) density during the reionization era is through the 21-cm emission experiments like GMRT, MWA and LOFAR. Measurement of the spatial distribution of neutral hydrogen via the redshifted 21-cm line promises to revolutionize our knowledge of the epoch of reionization and the first galaxies, and may provide a powerful new tool for observational cosmology from redshifts $1 < z < 4$. I have worked on a particular topic of constraining large scale HI bias using 21-cm signal from the post-reionization epoch.

Large Scale HI Bias using Redshifted 21-cm Signal

In the absence of complex astrophysical processes that characterize the reionization era, the 21-cm emission from neutral hydrogen (HI) in the post-reionization epoch is believed to be an excellent tracer of the underlying dark matter distribution. Assuming a background cosmology, it is modelled through (i) a bias function $b(k, z)$, which relates HI to the dark matter distribution and (ii) a mean neutral fraction ($\bar{x}_{\rm HI}$) which sets its amplitude. In this paper, we investigate the nature of large scale HI bias. The post-reionization HI is modelled using gravity only N-Body simulations and a suitable prescription for assigning gas to the dark matter halos. Using the simulated bias as the fiducial model for HI distribution at $z \leq 4$, we have generated a hypothetical data set for the 21-cm angular power spectrum (C_ℓ) using a noise model based on parameters of an extended version of the GMRT. The binned C_ℓ is assumed to be measured with SNR $\gtrsim 4$ in the range $400 \leq \ell \leq 8000$ at a fiducial redshift $z = 2.5$. We explore the possibility of constraining $b(k)$ using the Principal Component Analysis (PCA) on this simulated data (Guha Sarkar et al. 2012). Our analysis shows that in the range $0.2 < k < 2\ {\rm Mpc}^{-1}$, the simulated data set cannot distinguish between models exhibiting different k dependences, provided $1 \lesssim b(k) \lesssim 2$ which sets the 2-σ limits. This justifies the use of linear bias model on large scales. The largely uncertain $\bar{x}_{\rm HI}$ is treated as a free parameter resulting in degradation of the bias reconstruction. The given simulated data is found to constrain the fiducial $\bar{x}_{\rm HI}$ with an accuracy of $\sim 4\%$ (2-σ error). The method outlined here, could be successfully implemented on future observational data sets to constrain $b(k, z)$ and $\bar{x}_{\rm HI}$ and thereby enhance our understanding of the low redshift Universe.

3. Large Scale Structure Formation of the Universe

In the standard, hierarchical, cold dark matter (CDM) paradigm of cosmological structure formation, galaxy formation begins with the gravitational collapse of overdense regions into bound, virialized halos of dark matter (DM). Bound in the potential wells of dark matter halos, baryons proceed to cool, condense, and form galaxies. Understanding the fundamental properties and abundances of these dark matter halos is the first, necessary step in understanding the properties of galaxies. The subject area of formation of galaxies is quite involved in itself dealing with formation of non-linear structures and various processes. I have mainly worked in a specific topic of this field which is the excursion set approach to dark matter halo formation and halo clustering.

Formation rates of dark matter haloes

We derive an estimate of the rate of formation of dark matter haloes per unit volume as a function of the halo mass and redshift of formation. Analytical estimates of the number density of dark matter haloes are useful in modeling several cosmological phenomena. We use the excursion set formalism for computing the formation rate of dark matter haloes. We use an approach that allows us to differentiate between major and minor mergers, as this is a pertinent issue for semi-analytic models of galaxy formation. We compute the formation rate for the Press-Schechter and the Sheth-Tormen mass function. We show that the formation rate computed in this manner is positive at all scales (Mitra et al. 2011). We comment on the Sasaki formalism where negative halo formation rates are obtained. Our estimates compare very well with N-body simulations for a variety of models. We also discuss the halo survival probability and the formation redshift distributions using our method.

Publications:

1. Mitra, Sourav; Choudhury, T. Roy; Ferrara, Andrea, *Reionization constraints using principal component analysis*, MNRAS **413**, 1569, (2011)

2. Mitra, Sourav; Kulkarni, Girish; Bagla, J. S.; Yadav, Jaswant K., *Formation rates of Dark Matter Haloes,* BASI **39**, 563, (2011)

3. Pandolfi, S.; Ferrara, A.; Choudhury, T. Roy; Melchiorri, A.; Mitra, S., *Data-constrained reionization and its effects on cosmological parameters*, PhRvD **84**, 123522, (2011)

4. Mitra, Sourav; Choudhury, T. Roy; Ferrara, Andrea, *Joint quasar-cosmic microwave background constraints on reionization history*, MNRAS **419**, 1480, (2012)

5. Guha Sarkar, Tapomoy; Mitra, Sourav; Majumdar, Suman; Choudhury, Tirthankar Roy, *Constraining large scale HI bias using redshifted 21-cm signal from the post-reionization epoch*, MNRAS **421**, 3570, (2012)

Conference/Workshops Attended:

1. 7^{th} *International Conference on Gravitation and Cosmology (ICGC 2011)*, Goa, India, Dec. 14 – Dec. 19, 2011.

2. *Indian Conference on Cosmology and Galaxy Formation (ICCGF 2011)*, IISER Mohali, India, Nov. 05 – Nov. 07, 2011.

3. *David Workshop VI*, Scuola Normale Superiore, Pisa, Italy, Oct. 17 – Oct. 20, 2011.

4. *Confronting particle-cosmology with Planck and LHC (Indo-UK meeting)*, Pune, India, August, 2011.

5. 29^{th} *Astr. Soc. India (ASI) Scientific meeting*, India, February, 2011.

Visits to other Institutes:

1. Scuola Normale Superiore, Pisa, Italy, Oct. 03 – Oct. 21, 2011.

Lectures/Seminars:

1. *Joint QSO-CMB constraints on reionization history*, Indian Conference on Cosmology and Galaxy Formation (ICCGF 2011), Indian Institute of Science Education and Research (IISER), Mohali, India, November, 2011.

2. *Joint QSO-CMB constraints on reionization history*, David Workshop VI, Scuola Normale Superiore (SNS), Pisa, Italy, October, 2011.

3. *Reionization constraints using principal component analysis*, Center for Computational Chemistry and Cosmology (4C) Group, Scuola Normale Superiore (SNS), Pisa, Italy, October, 2011.

4. *Joint QSO-CMB constraints on reionization: Comparison with the WMAP7 and forthcoming Planck data*, Confronting particle-cosmology with Planck and LHC (Indo-UK meeting), Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, India, August, 2011.

5. *Observational constraints on reionization using principal component analysis*, 29^{th} ASI meeting, Pt. Ravishankar Shukla University, Raipur, India, February, 2011.

Satyanarayan Mukhopadhyay

Research Summary:

In this academic year I have followed up my earlier work on same-sign multilepton signatures at the Large Hadron Collider (LHC), and have devised suitable variables which can be measured experimentally to check the presence of Majorana neutralino and specific types of lepton-number violating couplings in a supersymmetric theory. In another direction, I have worked on the implications of CPT symmetry and the unitarity of the S-matrix on baryogenesis and leptogenesis, which are the possible mechanisms for generating the baryon asymmetry of the universe. In addition, I have studied jet angular correlations in events with a high mass bottom quark pair or a top quark pair and two jets at the LHC, resulting from the quantum interference of the different helicity states of the intermediate gluons, which can have implications in the determination of spin and CP properties of new particles.

Publications:

1. Satyanarayan Mukhopadhyay, Biswarup Mukhopadhyaya, *Same-sign trileptons at the LHC: A Window to lepton-number violating supersymmetry,* Physical Review D **84**, 095001, (2011)

Preprints:

1. Atri Bhattacharya, Raj Gandhi, Satyanarayan Mukhopadhyay, *Reanalysing the implications of CPT and unitarity for baryogenesis and leptogenesis,* arXiv:1109.1832 [hep-ph]

2. Kaoru Hagiwara, Satyanarayan Mukhopadhyay, *Azimuthal correlation among jets produced in association with a bottom or top quark pair at the LHC,* (in preparation)

Conference/Workshops Attended:

1. *IPMU-YITP School and Workshop on Monte Carlo Tools for LHC*, YITP, Kyoto University, Japan, 5-10 September, 2011.

Visits to other Institutes:

1. KEK Theory Center, Tsukuba, Japan, June-July, 2011.
2. KEK Theory Center, Tsukuba, Japan, September, 2011.

Saurabh Pradhan

Research Summary:

My work concentrates on various aspects of manganite physics. The substitution of oxygen isotope in these systems is known to give rise to a metal-insulator transition and large changes in the ferromagnetic Curie temperature. Using the two fluid model and incorporating the hybridization effects between the two classes of electrons comprising it, we study the isotope effect using a modified coherent potential approximation (CPA) that also includes the renormalization of Jahn-Teller energy in a self-consistent way. Another problem that I am working on is the spin wave spectrum of metallic A-type manganites and magnon induced orbital fluctuations in them. Parallely, I have been working on the anisotropic magnetc phases in orbitally degenerate double-exchange model and the effect of Coulomb interaction on nanoscale phase separation in manganites within the two-fluid model using exact diagonalization based Monte Carlo algorithm. I have also completed a project on the effect of disorder in the XY-model and studied the changes in quantum entaglement and related properties.

Publications:

Disorder overtakes Order in Information Concentration over Quantum Networks
with R. Prabhu, Aditi Sen De, Ujjwal Sen
Phys. Rev. A **84**, 042334 (2011)

Preprints:

Isotope Effect in Doped Manganites
with G. Venketeswara Pai
(in preparation)

Conference/Workshops Attended:

- ATHENA-2012 , India, April-2012.
- Quantum Monte Carlo methods at work for novel phases of matter, Italy, January-2012.
- The ICTS Condensed Matter Programme, India, December-2011.

- Workshop on Low Dimensional Quantum Systems, India, October-2011.
- International School on Topology in Quantum Matter, India ,July-211

Teaching assistant for the following course :

1. Quantum Mechanics I (Instructor : Ashoke Sen)
2. Condensed Matter Physics II (Instructor : G. Venketeswara Pai)
3. Statistical Mechanics (Instructor : G. Venketeswara Pai)

Sabyasachi Tarat

Research Summary:

I am trying to understand the properties of superconductors in lattice systems, through numerical simulations of simplified model Hamiltonians. The model Hamiltonians typically take into account an attractive interaction between up and down spin electrons (without worrying about whether they orignate through electron-phonon coupling or something else), homogeneous disorder through a random scalar potential at each site, as well as the presence of magnetic/non-magnetic impurities. This, coupled with a travelling cluster approach, enables us to treat large lattice systems of $O(40 \times 40)$, giving us unprecedented access to spatial correlations and thermal fluctuations in the systems.

Preprints:

1. S. Tarat and Pinaki Majumdar, *Pairing Fluctuations and Anolamous Transport above the BCS-BEC Crossover in the Two Dimensional Attractive Hubbard Model,* arxiv:1105.1156v1

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

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

Conference/Workshops Attended:

1. *ICTS Condensed Matter Programme*, Indian Institute of Science, Bangalore, India, December 2011

2. *International School and Conference on Functional Materials*, Harish Chandra Research Institute,Allahabad, India, March 2011.

Other Activities:

1. Teaching Assistant, Classical Mechanics (Instructor : Rajesh Gopakumar) , August-December, 2011.

Arunabha Saha

Research Summary:

We looked at the generalisation of topologically massive gravity (TMG) to higher spins, specifically spin-3. We found a special "chiral" point for the spin-three, analogous to the spin-two example, which actually coincides with the usual spin-two chiral point. But in contrast to usual TMG, there is the presence of a non-trivial trace and its logarithmic partner at the chiral point. The trace modes carry energy opposite in sign to the traceless modes. The logarithmic partner of the traceless mode carries negative energy indicating an instability at the chiral point. We make several comments on the asymptotic symmetry and its possible deformations at this chiral point and speculate on the higher spin generalisation of LCFT2 dual to the spin-3 massive gravity at the chiral point. We calculated the one loop partition function for topologically massive higher spin gravity (TMHSG) for arbitrary spin by taking the spin-3 TMHSG action constructed in arXiv:1107.0915 and subsequently generalising it for an arbitrary spin. We found that the final result can be put into a product form which cannot be holomorphically factorized giving strong evidence that the topologically massive higher spin gravity is dual to a high spin extension of logarithmic CFT rather than a chiral one.

Publications:

1. Arunabha Saha, Arjun Bagchi, Shailesh Lal, Bindusar Sahoo, *Topologically Massive Higher Spin Gravity,* JHEP **1110**, 150, (2011)
2. Arunabha Saha, Arjun Bagchi, Shailesh Lal, Bindusar Sahoo, *One loop partition function for Topologically Massive Higher Spin Gravity,* JHEP **1112**, 068, (2011)

Conference/Workshops Attended:

1. *Mini Workshop on Higher Spin Theories*, India, November 2011
2. *International Conference on Theoritical and Applied Physics*,,Inida, December 2011.
3. *National Strings Meet*,Inida, December 2011.
4. *Asian Winter School on Strings, Particles and Cosmology*,Japan, January 2012.

Nyayabanta Swain

Research Summary:

I have done some studies of the metal Mott-insulator transition in fermions in the Slave-rotor formalism. The study of repulsive Hubbard model at half-filling on a 2-dimensional square lattice has been carried out numerically. Both these works are done with Prof. Pinaki Majumdar. Another work on phenomenological theory for superconductivity in cuprates on 2-dimensional square lattice is under progress with Dr. G. V. Pai.

Conference/Workshops Attended:

1. *International Center for Theoretical Sciences (ICTS) Condensed Matter School and Conference*, IISc, Bangalore, India. Dec, 2011

Visits to other Institutes:

1. Raja Ramanna Center for Advanced Technology, Indore, India.

Rajarshi Tiwari

Research Summary:

In the current year I have focussed on 'pressure' driven Mott transition on magnetically frustrated systems, using Hubbard model on (i) anisotropic triangular lattice and (ii) FCC lattice. We study the half-filled Hubbard model on an anisotropic triangular lattice, with the anisotropy chosen to mimic the situation in the $\kappa-$(BEDT-TTF)$_2$ based organics. The model has a metal-insulator transition at a finite interaction strength, capturing which requires a non perturbative approach, and incommensurate magnetic correlations that require a real space treatment. We use a novel Monte Carlo method on large lattices, involving auxiliary magnetic moments coupled to the electrons, to solve this problem. Remaining at intermediate temperature we focus on the interaction driven transition, which mimics the pressure (or composition) driven transition in the organics, and demonstrate how the resistivity and optical response varies as the system is driven through the Mott transition. We predict a pseudogap phase, between the 'ungapped' metal and the 'hard gap' insulator, illustrate the momentum dependence of quasiparticle broadening and pseudogap formation, and correlate the electronic properties with incommensurate magnetic fluctuations in this frustrated system.
On FCC system, there is genuine tendency of the Hubbard model based system to order antiferromagnetically due to three dimension, though the frustration makes the nature of order non-coplanner, which is unexplored in the current context. Along with we explore Mott transition again through real space techniques, and highlight the key features particular to 3D FCC system.

Preprints:

1. Rajarshi Tiwari and Pinaki Majumdar, *A Real Space Description of the Transition from an Incoherent Metal to a Frustrated Mott Insulator,* in preparation

Conference/Workshops Attended:

1. *CECAM workshop on Quantum Monte Carlo methods at work for novel phases of matter*, Trieste Italy, January 2012,

2. *ATHENA-2012, An advance school on modelling complex oxides*, SNBNCBS Kolkata INDIA, April 2012.

Visits to other Institutes:

1. Max Plank Institute for Physics of complex systems (MPI-PKS), Dresden, Germany, February 2012

2. Liebnitz Institute of solid state material research (IFW), Dresden, Germany, February 2012

Invited Lectures/Seminars:

1. *Double exchange on geometrically frustrated lattice: Model and material motivated systems*, CMP Seminar, MPI-PKS, Dresden, Germany, February 2012.

2. *Incommensurate magnetic order and metal insulator transition in the Hubbard model on anisotropic triangular lattice*, ITF Seminar, IFW, Dresden, Germany, February 2012.

Manabendra Nath Bera

Research Summary:

I have joined the QIC group at HRI in February, 2012. During the academic year 2011-12, we have worked on several topics which can be devided in three parts.

First, we have investigated the multipartite entanglement behavior in the context of quantum phase transition (QPT) in a spin-$1/2$ XX chain with three-spin interaction. We have found that, a multipartite entanglement measure, called generalized geometric measure, is better indicator of QPT than the bipartite entanglement measures such as concurrence. It has been observed that the system may acquire a ground state which does not have bipartite entanglement while has a non-zero multipartite entanglement to indicate the quantum phase transitions.

Second, we have studied the quantum monogamy scores, which is a tripartite quantum correlation in terms of quantum discord, for W and GHZ class states. We find a necessary condition of vanishing discord monogamy score for arbitrary three-party states. A necessary and sufficient condition is obtained for pure states. We prove that the class of states having a vanishing discord monogamy score cannot have arbitrarily high genuine multipartite entanglement, as quantified by generalized geometric measure. In the special case of three-qubit pure states, their classification with respect to the discord monogamy score, reveals a rich structure that is different from that had been obtained by using the monogamy score corresponding to the entanglement measure called concurrence. We investigate properties like genuine multipartite entanglement and violation of multipartite Bell inequality for these states.

Third, we are currently investigating the bipartite and tripartite entanglement of three-qubit bosonic and fermionic systems when one or two subsystems are uniformly accelerated relative to the others. Due to the Unruh effect the bipartite entanglement of a bosonic systems goes to zero while it is not the case for the fermionic systems. In fact, the entanglement content decreases as the acceleration increases. It has been observed, for fermionic system, that the tripartite entanglement of two-subsystem-accelerated case decreases faster than the one-subsystem-accelerated and it reduces to the non zero minimum in the infinite acceleration. Further studies on the tripartite entanglement of the initial W and GHZ class states are in progress.

Preprints:

1. Manabendra N. Bera, R. Prabhu, Aditi Sen (De) and Ujjwal Sen, *Multisite entanglement: stronger indication of QPT with three-body interaction* , (in preparation).

2. Manabendra N. Bera, R. Prabhu, Aditi Sen (De) and Ujjwal Sen, *Classification of Tripartite states with Vanishing Monogamy Scores,* arXiv:1206.0172.

3. Manabendra N. Bera, Aditi Sen (De) and Ujjwal Sen, *Multiparty entanglement of fermions in an accelerated frame* , (in preparation).

Conference/Workshops Attended:

1. Local organizer of *Interantional Workshop in Quantum Information-2012*, India, February 2012.

Sourav Bhattacharya

Research Summary:

My research interest is general relativity and quantum field theory in curved spacetime. We have studied the no hair theorems for massive spin-2 and spin-$\frac{1}{2}$ fields for a stationary axisymmetric de Sitter black hole spacetime of dimension four endowed with two commuting Killing vector fields. By a de Sitter black hole spacetime we mean a black hole located inside a de Sitter Killing horizon. Our results hold for asymptotically flat spacetimes if reasonable fall-off condition at spacial infinity is assumed, as well as for asymptotically anti-de Sitter spacetimes if in addition to the fall-off condition we assume that the Compton wavelength of the spinor is less than the AdS length scale.

We have constructed a position dependent mass function in the exterior of the Schwarzschild-de Sitter black hole spacetime everywhere within the cosmological event horizon. In order to do this we have used the notion of total gravitational mass defined in a specific and suitable way. The mass function is positive definite and the Λ part monotonically increases as we move away from the black hole. This mass function is compatible with the geodesic motion and its variation gives the desired Smarr formula in terms of the two horizons' surface gravities. We also computed the particle spectra of a massless quantum scalar field corresponding to both the horizons in a suitable region between the two horizons. I have done the two above works with Prof. Amitabha Lahiri.

We are studying the time dependence induced on a four dimensional brane due to its motion along extra dimension(s) in some AdS spacetimes. This is known as mirage cosmology. The work is in progress with Prof. Dileep P. Jatkar and Prof. Debajyoti Choudhury.

I am trying to perform some calculations on the decay of a self interacting quantum massive scalar field in de Sitter spacetime using 'in-in' formalism. This is in progress with Prof. Dileep P. Jatkar.

We introduced a formalism to investigate the role of the spin angular momentum of astrophysical black holes in influencing the behaviour of general relativistic non self gravitating accretion at a very close proximity of the event horizon. We consider a four dimensional stationary axisymmetric spacetime with two commuting Killing vector fields and take general relativistic Euler and continuity equations. We have been able to show using symmetry arguments that if we restrict our attention to dimension three (for the flow), the fluid equation is completely separable analytically

and assuming the fluid equation of state, we can completely determine the components of the fluid velocity. This can be considered as a general framework for dealing with the fluid equations in rotating black hole spacetimes. We then provide the critically solutions for the stationary flow. By introducing a linearized perturbation scheme, we demonstrate that such transonic stationary solutions are stable. The properties of infalling material, for the prograde as well for the retrograde accretion, extremely close to the event horizon are studied as a function of the Kerr parameter, leading to the possibility of identifying a new spectral signature of black hole spin. The possibility of performing the black hole shadow imaging using direct VLBI measurement will also be explored. I have done this work with Prof. Tapas Kumar Das and others.

Preprints:

1. Sourav Bhattacharya and Amitabha Lahiri, *No hair theorems for stationary axisymmetric black hole spacetimes,* (in preparation).

2. Sourav Bhattacharya and Amitabha Lahiri, *Mass function for the Schwarzschild-de Sitter spacetime, thermodynamics and particle creation,* (in preparation).

3. Paramita Barai, Sourav Bhattacharaya, Bozena Czerny, Tapas K Das, Swathi Hegde, Ishita Maity, Sankhasubhra Nag, Tapan Naskar, and Paul J Wiita, *Behaviour of low angular momentum relativistic accretion close to the event horizon,* (in preparation).

Anindya Biswas

Research Summary:

I have begun working in the field of quantum information. More specifically I have worked in the interface of condensed matter physics and quantum information. I have worked on the J1-J2 model of quantum spin chains in one and two dimensions. The goal is to obtain measures of multi particle quantum entanglement which can manifest signatures of quantum phase transitions in such models. The problem reduces to finding the eigenvalues and eigenvectors of very large matrices. The size of the matrix depends on the number of particles in the system. The insufficient randomly accessible memory of the computer is a problem in finding these eigenvalues and eigenvectors. So I have used sparse matrix techniques together with Jacobi-Davidson algorithm in FORTRAN codes to find approximate eigenvalues and eigenvectors of Hamiltonians of twenty particles. More work in this direction is underway. I have also studied the Benford's law and its usefulness in detecting quantum phase transitions in various spin systems. I have also started working on resonating valence bond states with holes in ladder like spin systems, wherein the goal is to find the multi particle quantum entanglement. Some analytical work has been done and more work is underway.

I have also worked on ultracold trapped Bose gases using the Correlated Potential Harmonic Expansion Method where spectral fluctuation and noise in the energy level statistics of interacting trapped Bosons have been studied.

Preprints:

1. Kamalika Roy, Barnali Chakrabarti, **Anindya Biswas**, V. K. B. Kota and Sudip Kumar Haldar, *Spectral fluctuation and $\frac{1}{f^\alpha}$ noise in the energy level statistics of interacting trapped bosons,* arXiv:1112.3718 (to be published in Phys. Rev. E)

Conference/Workshops Attended:

1. *International Workshop on Quantum Information*, India, February 2012,
2. *International School and Conference on Quantum Information*, India, December 2011.

Visits to other Institutes:

1. Lady Brabourne College, Kolkata, India, December 2011.

Masahide Manabe

Publications:

1. Masahide Manabe, *Deformed planar topological open string amplitudes on Seiberg-Witten curve,* JHEP **1204**, 082, (2012).

Conference/Workshops Attended:

1. *National Strings Meeting 2011*, India, December, 2011.
2. *New Recursion Formulae and Integrability for Calabi-Yau Spaces*, Canada, October, 2011.

Akhilesh Nautiyal

Research Summary:

Observations show that our universe is homogeneous and isotropic at large scales. It contains 4% baryonic matter and the rest is dominated by dark matter and dark energy. This model is called as ΛCDM model of cosmology. Besides this, our universe also contains an uniform distribution of microwave radiation called as "cosmic microwave background radiation (CMBR)", which is coming to us from all directions and is perfectly consistent with a black body at the temperature of 2.75K. CMBR also has small anisotropies of the order of 10^{-5} and is polarized by 10%. There are lots of ongoing and planed experiments to measure CMBR anisotropy and polarizations like WMAP, PLANCK and CMBPOL etc.
The observed large scale homogeneity and isotropy can be achieved by an epoch of rapid expansion of the universe named as "inflation" in the early universe before Big-bang Neucleosynthesis. Inflation not only provides initial conditions for homogeneous, isotropic and flat universe but also gives rise to seeds for anisotropy and structures in the universe we are seeing today. Inflation is achieved by the potential energy of a scalar field (called inflaton), which dominates the total energy density of the universe. During this epoch, there are quantum fluctuations in the scalar field and the space-time metric that stretch out to all cosmological scales and give rise to the matter density perturbations and anisotropy in the CMB we are observing today. Inflation predicts adiabatic, nearly scale invariant and Gaussian perturbations that are consistent with the current CMB observations. Inspite of its success, we still lake a unique model of inflation that is constituent with some high energy physics theory.
In the last academic year, we mainly focussed on inflationary model building and constraining the various inflationary parameters with CMB anisotropy. There are large number of attempts to incorporate inflation in some high energy physics theory. One of them is warm inflation, where inflaton is coupled with the radiation, which is sub-dominant during inflation. But in these models, large dissipative couplings of the inflaton with radiation is required to keep radiation constant with respect to exponential expansion, These large couplings can de-stabilize the flatness of the inflaton potential due to radiative corrections. One way to suppress thee corrections without fine tuning unrelated couplings is by supersymmetry. We (H. Mishra, S. Mohanty and A. Nautiyal) showed that if the inflaton and other light fields are Pseudo-Nambu-Goldstone Bosons then the radiative corrections to the potential are suppressed and the thermal corrections are small as long as

the temperature is below the symmetry breaking scale. In such models it is possible to fulfill the contrary requirements of an inflaton potential which is stable under radiative corrections and the generation of a large dissipative coupling of the inflaton field with other light fields. We construct a warm inflation model which gives the observed CMB-anisotropy amplitude and spectral index where the symmetry breaking is at the GUT scale.

There are some models of inflation motivated from string theory named as "K-inflation", where inflation is achieved by the non-canonical kinetic terms of the scalar field. We (N. C. Devi, A. A. Sen and A. Nautiyal) studied these models with Dirac-Born-Infeld (DBI) form for the kinetic energy of the inflaton field. We consider quadratic and quartic potentials as well as the potential for the natural inflation. We use a modified version of the MODECODE (proposed by Mortonson et al.) to calculate the power spectrum of the primordial perturbations generated by the inflaton field and subsequently use the WMAP7 results to constrain the models. Interestingly with DBI type kinetic term, lesser gravity waves are produced as one approaches more towards scale invariance. This is true for all the potentials considered. Unlike the canonical case, this feature, in particular, helps the quartic ($\lambda\phi^4$) potential with DBI type kinetic term to be consistent with WMAP data.

As mentioned earlier that our current universe is dominated by dark energy that is causing accelerated expansion observed by Type IA supernova. Currently there is a variety of scalar field models to explain this late time acceleration of the universe. This includes the standard canonical and non-canonical scalar field models together with recently proposed Galileon scalar field models. One can divide all these scalar field models into two broad categories, namely the thawing and the tracker class. We (S. Thakur, A. Nautiyal, A. A. Sen and T. R. Seshadri) have investigated the evidence for these models with the presently available observational data using the Bayesian approach. We use the Generalized Chaplygin Gas (GCG) parametrization for dark energy equation of state (EoS) as it gives rise to both the thawing and tracking behaviours for different values of the parameters. Analysis of the observational data does not give any clear evidence for either thawing or tracking behaviour within the context of background cosmology, However, if we consider the evolution of inhomogeneities and analyze the data in this context then there is a significant evidence in favour of thawing behaviour.

Publications:

1. Hiranmaya Mishra, Subhendra Mohanty, Akhilesh Nautiyal, *Warm Natural Inflation,* Phys.Lett. B **710** , 245-250, (2012)

2. N. Chandrachani Devi, Akhilesh Nautiyal, Anjan A Sen, *WMAP Constraints On K-Inflation ,* Phys.Rev. D **84**, 103504, (2011)

Preprints:

1. Shruti Thakur, Akhilesh Nautiyal, Anjan A Sen, T R Seshadri, *Thawing Versus. Tracker Behaviour: Observational Evidence ,* arXiv:1204.2617

Conference/Workshops Attended:

1. *International 'Workshop on High Energy Physics and Phenomenology (WHEPP XII)*, Mahabaleshwar, India, January 2-8, 2012.

2. *International workshop on 'Dark Energy' (IWDE)*, CTP, Jamia Millia Islamia, Delhi India, December 21-23, 2011.

3. *International conference on 'Gravitation and Cosmology (ICGC)*, Goa, India, December 14-19, 2011.

4. *Indian conference on 'Cosmology and Galaxy Formation (ICCGF)*, IISER, Mohali, India, November 5-7, 2011.

Visits to other Institutes:

1. Theory Division, Physical Research Laboratory, Ahmedabad, India, November 21-28, 2011.

2. Centre for Theoretical Physics, Jamia Millia Islamia, Delhi, India, October 31-November 4, 2011.

3. IUCAA Resource Centre, University of Delhi, Delhi, India, September 5-15, 2011.

Invited Lectures/Seminars:

1. *Non-standard Models of inflation*, WHEPP XII, International Centre for Theoretical Sciences, Mahabaleshwar, India, January 2-8, 2012.

2. *Warm Natural Inflation*, ICGC, International Centre for Theoretical Sciences, Goa, India, December 14-19, 2011.

3. *WMAP Constraints On K-Inflation* , ICCGF Indian Institute of Science Education and Research (IISER), Mohali, Mohali, India, November 5-7, 2011.

4. *Warm Natural Inflation*, IUCAA Resource Centre, University of Delhi, Delhi, India, September 15, 2011.

Kenji Nishiwaki

Research Summary:

Universal Extra Dimension (UED) is one of the interesting possibilities in particle physics in context of extra spacial direction(s). One remarkable topics in UED is that heavy Higgs boson is allowed with considering constraints from S, T parameters. In this configuration, the theory predicts a very clear signal of "Higgs boson $\rightarrow$ two Z bosons $\rightarrow$ four charged leptons" with a resonant peak, which is an evident signal indicating existence of new physics. I and my collaborators analyzed this process in all the known "minimal" versions of UED models with one or two spacial directions and conclude that we can justify the signals by use of the data accumulated through a-few-years-long 14 TeV running at the LHC.

I and my collaborators also discussed the constraints on the models from experimental data of single Higgs boson production through gluon fusion and subsequent decays at the LHC. In any minimal UED model, the process of the single Higgs production is enhanced and parameter regions which predict too many signals coming from the process are excluded. The reason of the enhancement is contribution of KK particles to the production (and decay processes) and we can estimate the lower bound of the typical scale of KK particles in UED models. In UED models with two extra dimensions, this lower bound is severer than in models with one extra dimension and its concrete value is roughly 1 TeV.

Publications:

1. Kenji Nishiwaki, Kin-ya Oda, Naoya Okuda and Rroutaro Watanabe, *A bound on Universal Extra Dimension Models from up to 2fb^{-1} of LHC Data at 7TeV,* Physics Letter **B707**, 506, (2012)

2. Kenji Nishiwaki, Kin-ya Oda, Naoya Okuda and Rroutaro Watanabe, *Heavy Higgs at Tevatron and LHC in Universal Extra Dimension Models,* Physical Review **D85**, 035026, (2012)

Preprints:

1. Takuya Kakuda, Kenji Nishiwaki, Kin-ya Oda, Naoya Okuda and Rroutaro Watanabe, *Higgs at ILC in Universal Extra Dimensions in Light of Recent LHC Data,* Proceedings of International Linear Col-

lider Workshop (LCWS11), 26-30 September 2011, Granada, Spain, arXiv:1202.6231 [hep-ph]

Conference/Workshops Attended:

1. *QFT and String 2011*, Japan, July 2011.
2. *Summer Institute 2011 on hParticle physics Phenomenologyh*, Japan, August 2011.
3. *2011 IPMU-YITP School and Workshop on Monte Carlo Tools for LHC*, Japan, September 2011.
4. *Japan Physical Society Meeting*, Japan, September 2011.
5. *Think Tank on Physics @ LHC: Mote Carlo Event Generators at NLO and Jet Physics*, India, December 2011.
6. *the workshop "Extra Dimensions in the Era of the LHC"*, Japan, December 2011.
7. *Workshop on High Energy Physics Phenomenology XII*, India, January 2012.

Visits to other Institutes:

1. Osaka University, Osaka, Japan, December 2011.
2. Kobe University, Kobe, Japan, December 2011.

Invited Lectures/Seminars:

1. *Theoretical and Phenomenological Aspects of Dirichlet Higgs Model*, Invited talk at the seminar, Shinsyu University, Nagano, Japan, June 2011.
2. *New Types of universal extra dimensional models at Tevatron and LHC*, Poster presentation at the workshop "QFT and String 2011", Yukawa Institute for Theoretical Physics, Kyoto, Japan, July 2011.
3. *(New) Types of Universal Extra Dimension models with (Heavy) Higgs boson*, Short talk at Summer Institute 2011 on hParticle physics Phenomenologyh, Calm Fuji, Fuji-yoshida, Japan, August 2011.

4. *Consistency of non-zero Dirichlet boundary condition on bulk Higgs II*, Oral presentation at Japan Physical Society Meeting, Hirosaki University, Aomori, Japan, September 2011.

5. *Heavy Higgs at Tevatron and LHC in Universal Extra Dimension models*, Invited talk at the seminar, Kyoto University, Kyoto, Japan, September 2011.

6. *Future collider signals via golden channel and constraints from the latest data of 5D and 6D Universal Extra Dimension models in LHC*, Welcome seminar talk at HRI, Harish-Chandra Research Institute, Allahabad, India, November 2011.

7. *Higgs signals via golden channel at LHC in Universal Extra Dimensions with light/heavy Higgs*, Talk at the workshop "Extra Dimensions in the Era of the LHC", Osaka University, Osaka, Japan, December 2011.

Satoshi Ohya

Research Summary:

In the academic year 2011-2012, I worked on two subjects. The first is gauge theories on an interval. In collaboration with Y. Fujimoto et al. we found a novel spontaneous symmetry breaking mechanism induced by boundary localized mass terms. The second is path integrals on quantum graphs. I showed that weight factors of path integrals on compact graphs are generally given by multi-dimensional unitary representations of the infinite dihedral group.

Publications:

1. Yukihiro Fujimoto, Tomoaki Nagasawa, Satoshi Ohya, Makoto Sakamoto, *Phase Structure of Gauge Theories on an Interval,* Prog. Theor. Phys. **126**, 841-854, (2011)

2. Satoshi Ohya, *Path Integral on Star Graph,* Annals Phys. **327**, 1668-1681, (2012)

Preprints:

1. Satoshi Ohya, *Path Integral Junctions,* arXiv:1201.5115

Conference/Workshops Attended:

1. *Workshop on Low Dimensional Quantum Systems*, India, October, 2011,

2. *International Nonequilibrium Winter School*, India, December, 2011.

Visits to other Institutes:

1. Kobe University, Kobe, Japan, September, 2011.

Efunwande Osoba

Research Summary:

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

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

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

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

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

Publications:

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

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

Preprints:

1. Efunwande Osoba, *Fourth Generations with an Inert Doublet Higgs,* in preparation.
2. Efunwande Osoba, *The invisible Higgs Width in the Standard Model extended with Fifth generations* in preparation.

Conference/Workshops Attended:

1. *Lepton-Photon*, India, August 2011
2. *Nu Horizons*, India, Feb 2011

Andreas Nyffeler

Research Summary:

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

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

I continued to work on the long-term project of studying the hadronic light-by-light (had. LbyL) scattering contribution to the muon $g-2$. Whereas the evaluation of the hadronic vacuum polarization contribution to the muon $g-2$ is likely to be improved considerably in the next few years with new experimental data on the cross-section $e^+e^- \to$ hadrons at various colliders, the estimates of had. LbyL scattering are currently all based on hadronic models. This leads to large uncertainties in the Standard Model (SM) prediction for the muon $g-2$ and makes it difficult to interpret the presently observed deviation of about three to four standard deviations from the experimentally measured value. With several members from the KLOE Collaboration at the Daphne collider in Frascati, Italy, I found that the upcoming KLOE-2 experiment could measure, within one year of data taking, the $\pi^0 \to \gamma\gamma$ decay width to 1% statistical precision and the $\gamma^*\gamma \to \pi^0$ transition form factor for small spacelike momenta, $0.01 < Q^2 < 0.1$ GeV^2, to 6% statistical precision in each bin. In particular the width measurement will substantially reduce the uncertainty in the normalization of the transition form factor. This, in turn, will allow to reduce the error in the pion-exchange contribution to had. LbyL scattering, although in certain models the uncertainty in modelling the off-shell pion still largely dominates the overall error. This work is another step in the process to better control the hadronic uncertainties in the SM prediction of the muon $g-2$, which will in particular be important in view of new planned muon $g-2$ experiments at Fermilab, USA, and J-PARC, Japan, which aim at a factor of four-fold improvement in precision.

Publications:

1. D.K. Ghosh, A. Nyffeler, V. Ravindran *et al.*, *Working group report: Physics at the LHC,* Pramana **76**, 707, (2011)

2. D. Babusci, H. Czyz, F. Gonnella, S. Ivashyn, M. Mascolo, R. Messi, D. Moricciani, A. Nyffeler, G. Venanzoni and the KLOE-2 Collaboration, *On the possibility to measure the $\pi^0 \to \gamma\gamma$ decay width and the $\gamma^*\gamma \to \pi^0$ transition form factor with the KLOE-2 experiment,* Eur. Phys. J **C72**, 1917, (2012)

3. R. Basu, D. Indumathi, P. Mathews, A. Nyffeler, V. Ravindran (editors), *Proceedings of the 10th International Symposium on Radiative Corrections (Applications of Quantum Field Theory to Phenomenology),* PoS (Proceedings of Science) **RADCOR2011**, (2012)
http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=145

Conference/Workshops Attended:

1. *Advanced School on Radiative Corrections for the LHC*, SINP, Kolkata, India, April 2011.
Delivered two lectures and one tutorial on *Basics of perturbative QCD*: the strong interactions, QCD Lagrangian and Feynman rules, dimensional regularization, $\overline{\rm MS}$ renormalization of QCD to one loop, renormalization group and running of α_s.

2. *10th International Symposium on Radiative Corrections: Applications of Quantum Field Theory to Phenomenology (RADCOR 2011)*, Mamallapuram, India, September 2011.

3. *Think Tank on Physics@LHC: Monte Carlo Event Generators at NLO and Jet Physics*, Sariska, India, December 2011.

Visits to other Institutes:

1. Institute for Theoretical Physics, University of Bern, Switzerland, May - June 2011 (4 weeks).

Other Activities:

1. Together with V. Ravindran (HRI), R. Basu (IMSc, Chennai), D. Indumathi (IMSc, Chennai) and P. Mathews (SINP, Kolkata), I was on

the Organizing Committee for an "Advanced School on Radiative Corrections for the LHC" in April 2011 and the "10th International Symposium on Radiative Corrections - RADCOR 2011" in September 2011, funded with 35 lakhs Rupees by the International Centre for Theoretical Sciences (ICTS), TIFR, Mumbai. Continuing work from August 2009 - March 2011.

2. Responsibility of associateship and visitor programme of the Regional Centre for Accelerator-based Particle Physics (RECAPP) at HRI and help in organization of academic meetings of RECAPP (with A. Datta, B. Mukhopadhyaya and V. Ravindran), since May 2010.

3. Series of introductory lectures on "The Muon $g-2$" at HRI, January - May 2011.

4. Graduate course at HRI: Mathematical Methods 1, August - December 2011.

5. Pheno lunch (3 lectures): Higgs mass and vacuum stability, February 2012.

6. Referee for European Physical Journal C, Journal of High Energy Physics (JHEP), Physical Review D.

Binata Panda

Research Summary:

We looked at the logarithmic correction to the entropy of extremal black holes. We compute the second Seely-DeWitt coefficient of the kinetic operator of the metric and gauge fields in Einstein-Maxwell theory in an arbitrary background field configuration. We then use this result to compute the logarithmic correction to the entropy of an extremal Kerr-Newmann black hole.

Preprints:

1. Sayantani Bhattacharyya, Binata Panda and Ashoke Sen, *Heat Kernel Expansion and Extremal Kerr-Newmann Black Hole Entropy in Einstein-Maxwell Theory,* arXiv:1204.4061

Conference/Workshops Attended:

1. *Mini Workshop on Higher Spin Theories*, India, November 2011
2. *National Strings Meeting,* Inida, December 2011.
3. *Asian Winter School on Strings, Particles and Cosmology,* Japan, January 2012.

Visits to other Institutes:

1. Institute of Physics, Bhubaneswar, India, February 2012.

Invited Lectures/Seminars:

1. *Studying Blackhole Phase Transitions using Bragg-Williams Method*, National Strings Meeting, Delhi, India, December 2011 .
2. *Heat Kernel Expansion and Extremal Black Hole Entropy in Einstein Maxwell Theory*, High Energy Physics Seminar, Institute of Physics, Bhubaneswar, India, February 2012.

Suvrat Raju

Research Summary:

My research, in the academic year 2011-2012, focused on two aspects of the AdS/CFT correspondence. I continued my work on applying techniques developed to compute S-matrix elements in flat space to the computation of correlation functions in the AdS/CFT correspondence. Using this, I was able to calculate the four-point function of the energy-momentum tensor. Although this quantity is of considerable interest—since it is a universal observable that takes the same value in all conformal field theories with a gravity dual—it was inaccessible through conventional techniques and had not previously been calculated. Going the other way—from anti-de Sitter space to flat space—I also developed a new technique of extracting flat-space S-matrix elements from AdS/CFT correlators. I was able to use this to check my answer for the four-point stress-tensor correlator.

In separate work with Liam Fitzpatrick, Jared Kaplan, Joao Penedones, and Balt van Rees, I also worked on the use of "Mellin representations" to represent AdS/CFT correlators. We pointed out that performing a Mellin transform on conformal field theory correlators is, in some respects, analogous to performing a Fourier transform on ordinary field theory correlators and going to momentum space. Our formalism simplifies the bulk AdS-integrals that must be done to compute boundary correlators. As an example, we computed high-point correlators in a toy-scalar model—a calculation that would be prohibitively difficult without the use of Mellin variables.

I also worked on higher-spin theories in the AdS/CFT correspondence. Recently, Rajesh Gopakumar and Matthias Gaberdiel conjectured that when a new construction of higher spin theories, by Vasiliev, is adapted to AdS_3, it is dual to a particular "minimal" conformal field theory in two dimensions. This is interesting since both the CFT and the bulk theory are accessible at the same point in parameter space, and so we can use this to investigate questions about quantum gravity like information-loss. Together with Gopakumar, Gaberdiel, and Tom Hartman, we verified that, at infinite N, the partition function of the boundary theory contains the degrees of freedom of the bulk theory. In later work, with Kyriakos Papadodimas, we investigated some additional degrees of freedom in the boundary theory. We showed that these additional degrees of freedom are physically important, which raises the question of how they should interpreted in the bulk. This remains an area of active research.

Publications:

1. S. Raju, *Recursion Relations for AdS/CFT Correlators*, **Phys. Rev. D** 83, 126002 (2011).

2. M. Gaberdiel, R. Gopakumar,T. Hartman and S. Raju, *Partition Functions of Holographic Minimal Models*, **JHEP** 1108, 077 (2011).

3. A. L. Fitzpatrick, J. Kaplan, J. Penedones, S. Raju and B. C. van Rees, *A Natural Language for AdS/CFT Correlators*, **JHEP**, Vol. 2011, No. 11, 95.

4. K. Papadodimas and S. Raju, *Correlation Functions in Holographic Minimal Models*, **Nucl. Phys. B**, Vol. 856, No. 2, 607 (2012)

5. S. Raju and C. K. Raju, *Radiative Damping and Functional Differential Equations*, **Mod. Phys. Lett. A**, Vol. 26, No. 35, 2627 (2011).

Preprints:

1. S. Raju, *Four Point Functions of the Stress Tensor and Conserved Currents in AdS_4/CFT_3*, arXiv:1201.6452.

2. S. Raju, *New Recursion Relations and a Flat Space Limit for AdS/CFT Correlators*, arXiv:1201.6449.

3. K. Papadodimas and S. Raju, *An Infalling Observer in AdS/CFT*, (in preparation).

Conference/Workshops Attended:

1. *Back to the Bootstrap*, Perimeter Institute, Waterloo (Canada), April, 2011.

2. *Workshop on Higher Spins and Holography*, Harish-Chandra Research Institute, Allahabad, November 2011.

3. *National Strings Meeting*, Delhi University, December, 2011.

4. *Winter School on Fields and Strings*, Asia Pacific Center for Theoretical Physics, Pohang (Korea), February 2012.

5. *Amplitudes 2012*, DESY, Hamburg (Germany), March 2012.

Visits to other Institutes:

1. Perimeter Institute, Waterloo, Canada, April 2011.
2. Harvard University, Cambridge, USA, April 2011.
3. CERN, Geneva (Switzerland), June 2011.
4. ETH, Zurich (Switzerland), June 2011.
5. Institute for Advanced Study, Princeton, USA, June 2011.
6. Institute for Mathematical Sciences, Chennai, September 2011.
7. Chennai Mathematical Institute, November 2011.
8. Tata Institute of Fundamental Research, January 2012.
9. Brown University, February 2012.
10. Korea Institute for Advanced Study, Seoul (Korea), February 2012.

Invited Lectures/Seminars:

1. *BCFW Recursion in AdS*, Back to the Bootstrap, Perimeter Institute, Waterloo(Canada), April 2011.
2. *Recursion Relations for AdS/CFT Correlators*, String Seminar, Perimeter Institute, Waterloo (Canada), April 2011.
3. *Recursion Relations for AdS/CFT Correlators*, Duality Seminar, Harvard University, Cambridge (USA), April 2011.
4. *Recursion Relations for AdS/CFT Correlators*, String seminar, CERN, Geneva (Switzerland), June 2011.
5. *Recursion Relations for AdS/CFT Correlators*, String seminar, Institute for Advanced Study, Princeton (USA), June 2011.
6. *Holographic Minimal Models*, String Seminar, Institute of Mathematical Sciences, Chennai (India), September 2011.
7. *Recursion Relations for AdS/CFT Correlators*, String journal club, Institute of Mathematical Sciences, September 2011.

8. *Correlation Functions in Holographic Minimal Models*, Workshop on Higher Spins and Holography, Harish-Chandra Research Institute, Allahabad, November 2011.

9. *Computing AdS/CFT Correlators Efficiently*, National Strings Meeting, Delhi University, Delhi, December 2011.

10. *New Recursion Relations and a Flat Space Limit for AdS/CFT Correlators*, Duality Seminar, Tata Institute of Fundamental Research, Mumbai, January 2012.

11. *Four Point Correlators of the Stress Tensor in AdS_4/CFT_3*, String Seminar, Tata Institute of Fundamental Research, Mumbai, January 2012.

12. *Superconformal Algebras and their representations*, Winter School on Fields and Strings, Asia Pacific Center for Theoretical Physics, Pohang (Korea), February 2012.

13. *Four Point Functions of the Stress Tensor in AdS_4/CFT_3*, String Seminar, Korea Institute for Advanced Study, Seoul (Korea), February 2012.

14. *Four Point Functions of the Stress Tensor in AdS_4/CFT_3*, String Seminar, Brown University, Providence (USA), February 2012.

15. *Amplitude Techniques for AdS/CFT*, Amplitudes 2012, DESY (Hamburg), 2012.

Teaching

- Taught a reading course on *String Theory*, January–May 2011.
- Taught a second year course on *General Relativity*, August–December 2011.

Other Activities:

1. Referee for
   (a) Physical Review D
   (b) Journal of High Energy Physics
2. Wrote articles on issues of science and society for several newspapers and magazines throughout the year.

R. Prabhu

Research Summary:

During the academic year 2011-2012, I have carried out my research work on different aspects of quantum information theory in the multipartite regime. Specifically, I investigated the behavior of quantum correlation and its usefulness in different quantum information processing tasks in multiparticle systems by collaborating with other members of the Quantum Information and Computation group at HRI.

- We studied and compared the behaviors of a genuine multiparty entanglement measure, viz. the generalized geometric measure (GGM), and the quantum dense coding capacity of the ground state of the quenched disordered and ordered quantum XY spin chains. We found that there are distinct ranges of the disorder parameter that give rise to a higher genuine multiparty entanglement than in the corresponding systems without disorder: an order-from-disorder phenomenon in genuine multiparty entanglement.

- We considered the monogamy relation for the information-theoretic quantum correlation measure called quantum discord. We used the monogamy relation for quantum discord to provide a measure of multiparty quantum correlations and studied its relation with multiparty entanglement.

- We studied statistical mechanical properties of quantum correlation measures in XY spin models in different dimension. We discovered opposing statistical mechanical properties of the two major paradigms in which quantum correlation measures are defined, viz. the entanglement separability paradigm and the information-theoretic one. We show this by considering the ergodicity properties of these measures.

- We showed that the classical capacity of quantum states, as quantified by its ability to perform dense coding, respects an exclusion principle, for arbitrary pure or mixed three-party states in any dimension. This states that no two bipartite states which are reduced states of a common tripartite quantum state can have simultaneous quantum advantage in dense coding. The exclusion principle is robust against noise. Such principle also holds for an arbitrary number of parties.

Publications:

1. R. Prabhu, Saurabh Pradhan, Aditi Sen(De), and Ujjwal Sen, *Disorder overtakes order in information concentration over quantum networks,* Phys. Rev. A **84**, 042334, (2011)

Preprints:

1. R. Prabhu, Arun Kumar Pati, Aditi Sen(De), and Ujjwal Sen , *Conditions for monogamy of quantum correlations: Greenberger-Horne-Zeilinger versus W states,* arXiv:1108.5168 [quant-ph] (To appear in Phys. Rev. A (Rapid Communications))

2. R. Prabhu, Arun Kumar Pati, Aditi Sen (De), and Ujjwal Sen, *Light Cone-Like Behavior of Quantum Monogamy Score and Multisite Entanglement,* arXiv:1109.4318 [quant-ph]

3. R. Prabhu, Aditi Sen (De), and Ujjwal Sen, *Dual quantum correlation paradigms exhibit opposite statistical mechanical properties,* arXiv:1112.1856 [quant-ph]

4. R. Prabhu, Arun Kumar Pati, Aditi Sen (De), Ujjwal Sen, *Exclusion Principle for Quantum Dense Coding,* arXiv:1203.4114 [quant-ph]

Conference/Workshops Attended:

1. *Quantum Information Processing and Communication*, Zurich, Switzerland, September 2011.

2. *International School and Conference on Quantum Information*, Bhubaneswar, India, December 2011.

3. *International Workshop on Quantum Information*, Allahabad, India, February 2012.

Visits to other Institutes:

1. Department of Physics, Bangalore University, Bengaluru, India, June and November 2011.

Invited Lectures/Seminars:

1. *Monogamy of Quantum Correlations*, International School and Conference on Quantum Information, Institute of Physics, Bhubaneswar, December 2011.

2. *Dichotomy of the Two Quantum Correlation Paradigms*, International Workshop on Quantum Information, Harish-Chandra Research Institue, Allahabad, February 2012.

3. *Multiparticle Quantum Correlations*, HRI Physics colloquium, Harish-Chandra Research Institue, Allahabad, February 2012.

Other Activities:

1. Helped in conducting the talent search exam, held in November 2011, conducted by HRI for IX-X and XI-XII students of Allahabad.

2. Assisted the visiting summer students, Annwesha Dutta (DU, Delhi), Rini Ganguly (IIT Kanpur), and Sudipto Singha Roy (IIT Mumbai) to the QIC group.

3. Took part in organizing the International Workshop on Quantum Information which was held from 20 to 26 February 2012 at HRI.

Tapomoy Guha Sarkar

Research Summary:

The focus of my current research has been the possibility of using the redshifted 21-cm signal as a cosmological probe, towards understanding structure formation in the low redshift IGM. The research work done on various projects in the last year is summarised as follows

The Imprint of the Baryon Acoustic Oscillations (BAO) in the Cross-correlation of the Redshifted HI 21-cm Signal and Lyman$-\alpha$ Forest: The cross-correlation of the Ly-α forest and redshifted 21-cm emission has been proposed as an observational tool for mapping out the large-scale structures in the post-reionization era $z < 6$ with the significant advantage that problems of continuum subtraction and foreground removal are expected to be considerably less severe in comparison to the respective auto-correlation signals. In this work we have explored the possibility of using the cross-correlation signal to detect the standard ruler set by baryon acoustic oscillation (BAO). We have developed a theoretical formalism to calculate the expected cross-correlation signal and its variance. We have used this to predict the expected signal, and estimate the range of observational parameters where a detection is possible. [Collaborator(s): Prof. Somnath Bharadwaj (I.I.T Kharagpur, India)].

Constraining large scale HI bias using redshifted 21-cm signal from the post-reionization epoch: In the absence of complex astrophysical processes that characterize the era of cosmic reionization, the 21-cm emission from neutral hydrogen (HI) in the post-reionization epoch is believed to be an faithful tracer of the underlying dark matter density field. Assuming a background cosmology, it may be modelled through (i) a bias function $b(k, z)$, which relates HI to the dark matter distribution and (ii) a mean neutral fraction ($x_{\rm HI}$) which sets its amplitude. In this work, we investigate the nature of large scale HI bias. The post-reionization HI is modelled using gravity only N-Body simulations and a suitable prescription for assigning gas to the dark matter halos. Using the simulated bias as the fiducial model for HI distribution at $z \leq 4$, we have generated a hypothetical data set for the 21-cm angular power spectrum (C_l) using a noise model based on parameters of an extended version of the GMRT. We explore the possibility of constraining $b(k)$ using the Principal Component Analysis (PCA) on this simulated data. The method explored in this work, could be successfully implemented on future observational data sets to constrain $b(k, z)$ and $x_{\rm HI}$ and thereby enhance our understanding of the low redshift Universe. [Collaborators: Sourav Mitra (HRI), Suman Ma-

jumdar (I.I.T Kharagpur) and Dr. Tirthankar Roy Choudhury (HRI)].
Primordial Non-Gaussianity in the Forest: 3D Bispectrum of Ly-alpha Flux Spectra Along Multiple Lines of Sight: We investigate the possibility of constraining primordial non-Gaussianity using the 3D bispectrum of Ly-α forest. The strength of the quadratic non-Gaussian correction to an otherwise Gaussian primordial gravitational field is assumed to be dictated by a single parameter $f_{\rm NL}$. We present the first prediction for bounds on $f_{\rm NL}$ using Ly-α flux spectra along multiple lines of sight. The 3D Ly-α transmitted flux field is modeled as a biased tracer of the underlying matter distribution sampled along 1D skewers corresponding to quasars sight lines. We obtain bounds on $f_{\rm NL}$ for a range of observational parameters. The possibility of measuring $f_{\rm NL}$ at a precision comparable to LSS studies maybe useful for joint constraining of inflationary scenarios using different data sets. [Collaborators: Dhiraj Kumar Hazra (HRI)].
Metric deformation and eigenvalue problem in 2D for an irregular boundary: We prescribe a new formulation for solving the Helmholtz equation in 2D with irregular boundary. A suitable diffeomorphism is used to annul the asymmetries in the boundary by mapping it into an equivalent circle. This results in a modification of the metric in the interior of the region and manifests itself in the appearance of new gauge dependent source terms in the original homogeneous equation. The modified equation is then solved perturbatively. This method allows us to retain the simple form of the boundary condition at the cost of complicating the form of the original equation. It is seen to work reasonably well even for boundaries with large deviations from a circle by comparing our results with the exactly/numerically obtained ones. The Fourier representation of the boundary ensures the convergence of the perturbation series.[Collaborators: Subhasis Panda (I.I.T Kharagpur), S Pratik Khastgir (I.I.T Kharagpur)].

Publications:

1. Tapomoy Guha Sarkar, Sourav Mitra, Suman Majumdar, Tirthankar Roy Choudhury, *Constraining large scale HI bias using redshifted 21-cm signal from the post-reionization epoch,* Monthly Notices Of the Royal Astronomical Society **421**, 3570, (2012) arXiv:1109.5552.

2. Subhasis Panda, Tapomoy Guha Sarkar, S Pratik Khastgir, *Metric deformation and eigenvalue problem in 2D for an irregular boundary,* Progress in Theoretical Physics **127**, 1, (2012) arXiv:1106.5707.

Preprints:

1. Tapomoy Guha Sarkar, Somnath Bharadwaj, *The Imprint of the Baryon Acoustic Oscillations (BAO) in the Cross-correlation of the Redshifted HI 21-cm Signal and the Ly-α Forest,* arXiv:1112.0745.

2. Dhiraj Kumar Hazra, Tapomoy Guha Sarkar, *Primordial Non-Gaussianity in the Forest: 3D Bispectrum of Ly-$alpha$ Flux Spectra Along Multiple Lines of Sight,* arXiv:1205.2790.

Conference/Workshops Attended:

1. *International Conference on Theoretical and Applied Physics [ICTAP], I.I.T Kharagpur*, India, $1-2$ December, 2011.

2. 7^{th} *International Conference on Gravitation and Cosmology [ICGC2011], Goa*, India, $14-19$ December, 2011.

Pooja Srivastava

Research Summary:

The successful synthesis[1] of h-$(BN)_xC_y$ has opened new possibilities in the area of nano-electronics. These hybrid materials have tunable properties (e.g. band gap), intermediate to that of the precursors— graphene (gapless) and h-BN (bandgap ~ 6 eV). As the metal contacts are an integral part of any nano electronics device, we have studied the adsorption of transition metal (TM) atoms (Fe, Co and Ni) on h-BNC_2 sheet using density functional theory (DFT). The system becomes a magnetic semiconductor, semi-metal, or a non-magnetic semiconductor after adsorbing Fe, Co and Ni adatom respectively. We have found that TM adatoms are highly mobile on this sheet even at moderate temperatures. It is also energetically favorable for them to agglomerate together.

The electronic and magnetic properties of h-BNC_2 can be modified significanctly with the help of controlled defect engineering. We have studied the stability of h-BNC_2 sheet containing single and double vacancies and, Stone-Wales defects (rotation of a bond about it's centre of mass). We find that defects are comparatively more stable at the interface as compared to defects inside the graphene and h-BN region. We have also studied the diffusion of single vacancies and Stone-Wales defects at interface. Also some defects induce magnetic moment. Stable and tunable magnetism in h-BNC_2 will lead to many technological applications.

On the basis of local density approximation (LDA) calculation within DFT, $PbPd_{0.75}Co_{0.25}O_2$ (PPCO) has been proposed as spin gapless-semiconductor (SGS)[2]. In SGS both electron and hole can be fully spin polarized. Pure $PbPdO_2$ (PPO) is known to have gapless band structure. But there is no experimental proof for this claim that PPCO is a SGS. To understand the origin and evolution of SGS feature with doping, we did calculations and found that SGS feature is not robust under different approximations for the exchange correlation (XC) potential. Even for the PPO, different XC functional give contradictory results. It leads us to the conclusion that DFT fails for this particular material.

[1] L. Ci, et. al., Nat. Mater. **9**, 430 (2010).
[2] X. L. Wang *Phys. Rev. Lett.* **100** 156404 (2008).

Publications:

1. Pooja Srivastava, Mrinalini Deshpandey and Prasenjit Sen, *First-principles study of electronic and magnetic properties of transition metal adsorbed h-BNC_2 sheets,*, **13**, Phys. Chem. Chem. Phys. **13**, 21593 (2011)

2. Pooja Srivastava, B J Nagare, Dilip G Kanhere and Prasenjit Sen, *Predicting spin-gapless semiconductors: the case of $PbPdO_2$,* submitted to J. Phys.: Condens. Matter

Preprints:

1. Pooja Srivastava and Prasenjit Sen, *Stability of defects in h-BNC_2 sheets,* (in preparation)

Conference/Workshops Attended:

1. *International Symposium on Clusters and nano-scale Materials,*, India, November, 2011

2. *ATHENA*, India, April 2012.

Itzadah Thongkool

Research Summary:

During the academic year 2011-2012, I mainly worked on three topics in cosmology and string theory - quintessential inflation, reheating of twisted inflation and the quantum stability of the $f(R)$ gravity models.

One of the most remarkable discoveries in astrophysics is the accelerated expansion of the universe. Within the framework of general relativity, the cosmic acceleration can be explained by simply adding the cosmological constant to the models. However, due to its un-evolving nature, the cosmological constant must be set to an extremely small value in order to dominate the expansion dynamics of the universe at precisely the present epoch. This leads to a fine-tuning problem or cosmic coincidence problem. To alleviate this problem, the quintessence fields which couple minimally to gravity and which roll down a steep potential were introduced. The energy density of quintessence need not to be very small with respect to other components in the early universe. There is the special behaviour of the quintessence system so-called tracker solutions corresponding to attractor-like solutions in which the field energy density tracks the background fluid density for a wide range of initial conditions. One of the major drawbacks of quintessence is that we need another weakly interacting scalar field. Why can't we use one of those scalars already existing in the inflation epoch ?

There is the interesting proposal by Peebles and Vilenkin which making use of a potential for the field ϕ which allowed it to play the role of the inflaton in the early universe and later play the role of the quintessential field. It is important to note that the potential required does not have a minimum in which the reheating process can occur efficiently as in the case of the chaotic inflation. Reheating after quintessential inflation should have proceeded via gravitational particle production, but this mechanism is very inefficient. Another problems facing of this model is that the potential is simply constructed to solve the problem by hand, namely to give two periods of inflation at early and late times. As such, it is non-renormalizable.

The challenge for the realistic construction of quintessential inflation is that we need to find a flat potential during inflation but also require a steep potential during the radiation and matter dominated periods. We have found that the hilltop potential, in which inflation takes place near a maximum of the potential is suitable for the requirements. After infla-

tion, the steep potential is benefit for the efficient reheating, so called instant preheating and at the asymptotic region the scalar field can continue rolling slowly as quintessence.

We also study the possibility to have an efficient preheating for a new slow-roll inflation based on higher dimensional supersymmetric gauge theory compactified to four dimensions with twisted (supersymmetry breaking) boundary conditions (arXiv:1004.5385). The theory has two dimensionless parameters: the 't Hooft coupling λ in the 3+1 dimensional gauge theory at the Kaluza-Klein scale $1/R$, and the parameter N, the rank of gauge group. When λ is small, the model is weakly coupled at Kaluza-Klein scale M_{KK}, the effective potential for the large ϕ has the minimum so the conventional preheating process can be applied. For large λ, a more geometrical language is appropriate in describing the inflationary model. The degrees of freedom in the unbroken part of the gauge theory are well described by type IIA supergravity on a background. In the case of strong coupling $(\lambda \gg 1)$ the field redefinition gives a canonically normalized scalar field with the effective potential which does not has the minimum. It is possible to apply the instant preheating for this case.

The third topic we study the $f(R)$ gravity theories where the standard Einstein-Hilbert gravitational Lagrangian is replaced by a function of R. Now we know that viable $f(R)$ theories must satisfy stringent conditions in order to avoid instabilities and to satisfy the present laboratory and solar system constraints. $f(R)$ models are belong to the class modified gravity theories which are equivalent to the scalar-tensor theories with one scalar field then we can employ various techniques from the scalar-tensor theories to test them. It has been realized that the scalar tensor theories with the field strongly coupling to matter lead to a "fifth force" which is tightly constrained by observations. Khoury and Weltman have suggested that one can evade the fifth force constraints by giving the scalar field mass depending on the local density of matter background.This behaviour is called *chameleon mechanism*. For this reason, the $f(R)$ theories must be the chameleon theories for passing the gravitational tests. We use conformal transformation to change the $f(R)$ action in Jordan frame to be the chameleon theories action in Einstein frame and have found that the mass of scalar field grows too fast in the background density which leads to the violation of the quantum stability bound.

Preprints:

1. Sudhakar Panda, M. Sami & Itzadah Thongkool, *Quantum stability of $f(R)$ gravity theories*, (in preparation), (2012)

Conference/Workshops Attended:

1. *7th International Conference on Gravitation and Cosmology*, organized by ICTS, India, December, 2011

2. *International Workshop on Dark Energy*, organized by CTP, Jamia Millia Islamia, December, 2011

Visits to other Institutes:

1. Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi, India, October, 2011

2. Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi, India, January, 2012

Kouhei Hasegawa

1. I published the following paper with my collaborators.

Title : Anomalous Higgs Interactions in Gauge-Higgs Unification

Authors : K. Hasegawa, Nobuaki Kurahashi, C. S. Lim, Kazuya Tanabe

Date of submission : 24 Jan 2012

arXiv : 1201.5001v1 [hep-ph]

Report number : KOBE-TH-12-03, HRI-P-12-01-001

Subject : High Energy Physics - Phenomenology (hep-ph)

Comments : 29 pages, 8 figures

Abstract : We discuss anomalous Higgs interactions in the scenario of gauge-Higgs unification. In the scenario Higgs originates from higher dimensional gauge field and has a physical meaning as AB phase or Wilson loop. As its inevitable consequence, physical observables are expected to be periodic in the Higgs field. In particular, the Yukawa coupling is expected to show some periodic and non-linear behavior as the function of the Higgs VEV. For a specific choice of the VEV, the Yukawa coupling of KK zero mode fermion even vanishes. On the other hand, the Yukawa coupling is originally provided by gauge interaction, which is linear in the Higgs field. We discuss how such two apparent contradiction about the non-linearity of the Yukawa coupling can be reconciled and at the same time how these two "pictures" give different predictions.

1. I gave the following talk with some notes at Pheno-lunch.

Title : A basic of dipole subtraction

Speaker : K. Hasegawa

Date : 01.05.2012

Reference : hep-ph/9605323, hep-ph/0201036

Abstract : The main and typical theoretical predictions of LHC experiments are the various differential cross sections of various multi-parton

processes. The accuracy of next-leading-order in perturbative expansion of QCD coupling constants are required for the precise comparison with the experimental results. The Catani-Seymour dipole subtraction is a general and practical procedure for QCD NLO prediction. The procedure makes the prediction of multi-parton processes possible. In this talk I explained how the procedure makes it possible.

Joint Colloquia

1. Harald Upemeier: Holomorphic Quantization and Relations to Mathematical Physics.

2. Anil Kumar: Quantum Information Processing by NMR: Introduction, Past and Recent Developments.

Mathematics Talks and Seminars

1. Carlo Gasbarri: What is abc conjecture?
2. Drazen Adamovic: Vertex algebras and infinite-dimensional Lie algebras.
3. Harald Upemeier: Inversion of Radon Transform and Non-Convex Cones.
4. Hemangi Shah: On Asymptotically Harmonic Spaces.
5. Hemangi Shah: Flatness of Harmonic Manifolds with Minimal Horospheres.
6. Mathai Varghese: T-duality- an introduction.
7. Ashish Gupta: Algebras of quantum Laurent Polynomials.
8. Mukund Madhav Mishra: Dirichlet Problem on the Heisenberg Group.
9. Jaban Meher: On Generalized Modular Forms.
10. Karam Deo Shankhadhar: On the restriction map for Jacobi forms.
11. Umesh Dubey: Spectrum of tensor triangulated categories.
12. Makoto Minamide: The truncated Voronoi formula for the derivative of the Riemann zeta function.
13. R. Parthasarathy: Some remarks on Konstant's work on Lie algebra cohomology and Bott-Borel-Weil theorem.
14. Michel Waldschmidt: Diophantine Approximation and Diophantine Equations.
15. Hiroyuki Yamane: Shapovalov determinants via Weyl groupoids.
16. Claire Levailliant: Invariant subspaces of the Cohen-Wales reprensentation of the Artin group of type Dn.
17. Hiroyuki Yamane: Shapovalov determinants via Weyl groupoids - II.
18. Mahesh Nerurkar: Dynamical Systems and Combinatorial Number Theory.

19. J. Tilouine: Congruences between Modular Forms.
20. M. Waldschmidt: Transcendental Numbers.
21. Mahan Maharaj: Geometry and Dynamics of Kleinian groups.
22. Hiroyuki Yamane: Dynkin diagrams of simple Lie superalgebras and Wely groupoids.
23. Hiroyuki Yamane: Irreducible representations of generalized quantum groups.
24. Imre Katai: Set of Uniqueness for Arithmetical functions.
25. Bui Minh Phong: Pn the pairs of multiplicative functions with a special relation.
26. Roy Joshua: Algebraic cycles and Motives.
27. S.G. Dani: INSA Srinivasa Ramanujan Medal Lecture.

Physics Talks and Seminars

1. Dharmadas Jash: A brief overview of Neutron stars and Pulsars.
2. Raghunath Ghara: Pulsars.
3. Sanjit Das: Geometric flows without and with higher order and higher derivative terms.
4. Sudipta Sarkar: Black hole Membrane Paradigm.
5. Pooja Srivastava: Defect controlled band-gap engineering in Gapless Semiconductors: A DFT study.
6. Sourav Mitra: Reionization constraints using principal component analysis.
7. Tapomoy Guha Sarkar: The post - reionization neutral hydrogen - a cosmological probe.
8. Akhilesh Nautiyal: Warm natural inflation.
9. Paramita Barai: Simulating Active Galaxy Outflow Propogation and Metal Enrichment on Cosmological Scales.
10. Sudhir Sachdev: Quantam criticality of metals, and the high temperature superconductors.
11. Sudhir Sachdev: The superfluid-insulator quantam phase transition: field theory vs. holography.
12. M.A. Vasiliev: Higher-Spin gauge theory: from free fields to interations.
13. M. Gaberdiel: Minimal Model Holography.
14. X.Yin: Correlation Functions in Higher Spin Gauge Theories.
15. M. Sivkumar: Vasiliev Equation for higher spins.
16. Soumitra SenGupta: Some Phenomenological Implications of Multiple warped Geometry.
17. Sayantani Bhattacharya: Constraints on Second-Order Transport Coefficient of Uncharged Fluids.

18. Satoshi Ohya: The Hawking-Unruh phenomenon on graphene.

19. Bernard De Wit: BPS Near-Horizon Geometry of 5D Spinning black holes and the 4D/5D Connection.

20. Suvrat Raju: Correlation Functions in AdS_4/CFT_3.

21. Jaehyuk Oh: $SU(2)$ Yang-Mills on Ad_4 and its Boundary Aspects.

22. Jae-Hyuk Oh: Analytic Approaches to An-Isotropic Holographic Superfluids.

23. Anirban Kundu: Why B-physics?

24. Pradipta Bandyopadhyay: Development and application of Monte Carlo based techniques to understand energy landscapes of large molecules.

25. Saurabh Pradhan: Coulomb Interactions and Nanoscale Inhomogeneities in Manganites.

26. S. Balakrishnan: Characterization of Two-Qubit Gates.

27. Jonathan Oppenheim: Fundamental limitations for quantum and nano thermodynamics.

28. Bruce Mellado: Recent results from Higgs searches at the LHC.

29. J.V. Narlikar: Facts and Speculations in Cosmology.

30. Shiraz Minwalla: Hydrodynamics and Gravity.

31. Kedar Damle: Geometrically Frustrated Antiferromagnets.

32. Arnab Rai Chaoudhuri: The origin of the sunspot cycle.

33. Anshuman Maharana: Phenomenology in Type IIB String Theory.

34. Trilochan Bagarti: Reaction diffusion models of pattern formation at nanoscales.

35. U A Yajnik: Does spontaneously broken parity suggest an intermediate scale.

Recent Graduates

1. **Manimala Mitra**, *Neutrinos and some aspects of Physics beyond the standard model*.

2. **Sanjoy Biswas**, *Unveiling some supersymmetric scenarios using Tau-Leptons at the Large Hadron Collidor*.

3. **Ipsita Mandal**, *Aspects of supersymmetric Black Holes and Galilean Conformal Algebras*.

4. **Joydeep Chakraborty**, *Some Aspects of Grand Unified Theory: gauge coupling unification with Dimension-5 operators and neutrino masses in an SO (10) model*.

5. **Girish P. Kulkarni**, *Evaluation of Galaxies and the Intergalactic Medium at High Redshift*.

6. **Bhavin K. Moriya**, *Some Zero Sum Problems in Combinatorial Number Theory*.

7. **Mohan N. Chintamani**, *Weighted Subsequence Sums in Finite Abelian Groups*.

8. **Archana Subhas Morye**, *On the Serre-Swan Theorem and on Vector Bundles over Real Abelian Varieties*.

Publications

Sukumar Das Adhikari

1. Sukumar Das Adhikari and Mohan N. Chintamani, *Number of weighted subsequence sums with weights in* $\{1, -1\}$, Integers **11**, paper A 36, (2011).

2. Sukumar Das Adhikari, David J. Grynkiewicz, and Zhi-Wei Sun, *On Weighted Zero-sum Sequences,* Advances in Applied Mathematics **48**, 506-527, (2012).

Kalyan Chakraborty

1. Kalyan Chakraborty and Jay Mehta, *A Stamped Blind Signature Scheme based on Elliptic curve Discrete Log Problem*, Appear in International Journal of Network Security.

2. Kalyan Chakraborty and Jay Mehta, *On completely multiplicative complex valued funtions*, Annales Univ. Sci. Budapest, Sect. Comp. No. 38 (2012).

3. K Chakraborty, S. Kanemitsu and H. Tsukada, *Arithmetical Fourier series and the modular relation*, Kyushu J. Math., Vol.66, No.2, (2012).

4. Kalyan chakraborty, Imre Katai and Bui Minh Phong, *On real valued additive functions modulo 1*, Annales Univ. Sci. Budapest, Sect. Comp. No. 36 (2012), 355–373.

5. K. Chakraborty, S. Kanemitsu and X.-H. Wang, *The modular relation and the digamma function*, Kyushu J. Math., 65, (2011), 39–53.

Rukmini Dey

1. Rukmini Dey and Pradip Kumar, *One parameter family of solitons from minimal surfaces,* accepted in Proceedings of Indian Academy of Sciences; arxiv:1204.5875

2. S. Agarwal, T.K. Das, R. Dey and S. Nag , *An Analytical Study on the Multi-critical Behaviour and Related Bifurcation Phenomena for Relativistic Black Hole Accretion ,* accepted in General Relativity and Gravity

Ramakrishnan B.

1. B. Ramakrishnan, *A note on special values of certain Dirichlet L-functions,* Bull. Aust. Math. Soc. **83**, 435–438, (2011)

2. Sanoli Gun and B. Ramakrishnan, *The theta operator and the divisors of modular forms,* 'Number Theory', Ramanujan Math. Soc. Lect. Notes. Ser.,**15**, 17–30, (2011)

3. M. Manickam and B. Ramakrishnan (Eds.), *Number Theory,* Ramanujan Mathematical Society Lecture Notes Series, Number **15**, (Proceedings in Honour of Prof. T.C. Vasudevan on his Sixtieth Birthday), Ramanujan Mathematical Society, India 2011.

Ratnakumar Peetta Kandy

1. Ratnakumar P.K. and Saurabh Shrivastava, *On Bilinear Littlewood-Paley Square functions,* Proceedings of AMS (To appear) (2012)

R. Thangadurai

1. R. Thangadurai and A. Vatwani, *The least prime p congruent to 1 modulo n*, Amer. Math. Monthly **118**, 737-742, (2011)

2. M. N. Chintamani, W. D. Gao, B. K. Moriya, P. Paul and R. Thangadurai, *On Davenport's Constant,* Arch. Math **98**, 133-142, (2012)

3. M. Ram Murty and R. Thangadurai, *On a paper of S. S. Pillai,* Proc. Indian Acad. Sci. (Math. Sci.), **122**, 1-13, (2012)

Manoj Kumar

1. Manoj K. Yadav, *Class preserving automorphisms of finite p-groups - A Survey*, Proc. Groups St. Andrews (Bath) 2009, LMS Lecture Note Series **388**, 569 - 579, (2011).

2. Vivek Kumar Jain and Manoj K. Yadav, *On finite p-groups whose automorphisms are all central*, Israel J. Math. **189**, 225 - 236, (2012).

3. V. Bardakov, A. Vesnin and Manoj K. Yadav, *Class preserving automorphisms of unitriangular groups,* Internat. J. Algebra Comput. **22**, 17 pages, (2012) (DOI: 10.1142/S0218196712500233).

Satya Deo

1. Satya Deo, *Index of a finitistic space and a generalization of the topological central point theorem*, The journal of Ramanujan Mathematical Society, to appear, 2012

Pradip Kumar

1. **Rukmini Dey, Pradip Kumar**: One Parameter Family Of Solitons From Minimal Surfaces: *it discusses various new soliton arising from minimal surface* Accepted for publication in Proceedings of Mathematical sciences, Indian academy of sciences.

Jay Gopalbhai Mehta

1. Kalyan Chakraborty and Jay Mehta, *A Stamped Blind Signature Scheme based on Elliptic curve Discrete Log Problem,* accepted in International Journal of Network Security.

2. Kalyan Chakraborty and Jay Mehta, *On completely multiplicative complex valued funtions,* accepted in Annales Uni. Sci. Budapest. Sectio Comput.

Umesh Vanktesh Dubey

1. Umesh Dubey, Amritanshu Prasad and Pooja Singla, *The Cartan matrix of a centralizer algebra,* Proc. Indian Acad. Sci. (Math. Sci.) **122(1)**, 67-73, (2012)

Saikat Chatterjee

1. Indranil Biswas, Saikat Chatterjee *Flat connections on punctured surfaces and geodesic polygons in a Lie group,* Bull. des Sciences Math. **136**, 37-43, (2012)

Saurabh Kumar Shrivastava

1. Saurabh Shrivastava and P. K. Ratnakumar, *On bilinear Littlewood-Paley square functions,* Proc. Amer. Math. Soc. to appear.

Anirban Basu

1. Anirban Basu, *Supersymmetry constraints on the R^4 multiplet in type IIB on T^2* Class. Quant. Grav. **28**, 225018, (2011)

Sandhya Choubey

1. Sandhya Choubey, *Physics with India-based Neutrino Observatory,* AIP Conf.Proc. **1405**, 323, (2011)

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

3. Sandhya Choubey, Thomas Schwetz, Patricia Vahle, *Summary of the Oscillation Physics Working Group,* AIP Conf.Proc. **1382**, 77, (2011)

4. Sandhya Choubey, Pasquale Migliozzi, *Branch III: Oscillations at high energies*, Nucl.Phys.Proc.Suppl. **217**, 371, (2011)

5. LENA Collaboration, *The next-generation liquid-scintillator neutrino observatory LENA*, Astropart.Phys. **35**, 685, (2012)

Tapas Kumar Das

1. Tapas Kumar Das & Bożena Czerny, *On the efficiency of the Blandford-Znajek mechanism for low angular momentum relativistic accretion,* Monthly Notices of the Royal Astronomical Society Letters **421**, L24, (2011)

2. Shilpi Agarwal, Tapas Kumar Das, Rukmini Dey & Sankhasubhra Nag, *An analytical study on the multi-critical behaviour and related bifurcation phenomena for relativistic black hole accretion,* General Relativity & Gravitation (**Online First Edition**), DOI: 10.1007/s10714-012-1358-z, (2012)

3. Bożena Czerny, Pawel Lachowicz, MichałDovčiak, Vladimír Karas, Thomas Pecháček & Tapas Kumar Das, *QPO in RE J1034+396: model constraints from observed trends,* Journal of Physics (JPCS), (**to appear**), `arXiv:1202.2087v1 [astro-ph.CO]`, (2012)

4. Tapas Kumar Das, *Accreting Astrophysical Black Holes are Natural Examples of Classical Analogue Model,* Proceedings of the Twelfth Marcel Grossmann Meeting on General Relativity, edited by Thibault

Damour, Robert T. Jantzen and Remo Ruffini. ISBN 978-981-4374-51-4. Singapore: World Scientific **p. 1189**, (2012)

5. Hung-Yi Pu, Ishita Maity, Tapas Kumar Das & Hsiang-Kuang Chang, *On Spin Dependence of Relativistic Acoustic Geometry,* Classical and Quantum Gravity (**under review**), `arXiv:1204.1347v1 [gr-qc]`, (2012)

6. Neven Bilič, Arpita Choudhary, Tapas Kumar Das & Sankhasubhra Nag, *The role of axisymmetric flow configuration in the estimation of the analogue surface gravity and related Hawking like temperature,* Journal of Cosmology & Astroparticle Physics (**under review**), `arXiv:1205.5506v1 [gr-qc]`, (2012)

7. Bożena Czerny, Vladimír Karas, Devaky Kunneriath & Tapas Kumar Das, *Mini-spiral as source of material for Sgr A* in bright state,* Astronomy & Astrophysics (**under review**), `Preprint: available at http://www.hri.res.in/∼tapas/devaki.pdf/`, (2012)

8. Paramita Barai, Sourav Bhattacharaya, Bożena Czerny, Tapas Kumar Das, Swathi Hegde, Ishita Maity, Sankhasubhra Nag, Tapan Naskar & Paul J Wiita. *Behaviour of low angular momentum relativistic accretion close to the event horizon,* (In Preparation), (2012)

Aditi Sen De

1. S. Braungardt, M. Rodríguez, A. Sen(De), U. Sen, and M. Lewenstein, *Atom Counting in Expanding Ultracold Clouds*, Phys. Rev. A **84**, 043635 (2011).

2. A. Sen(De) and U. Sen, *Benford's Law Detects Quantum Phase Transitions similarly as Earthquakes*, Europhys. Lett. **95**, 50008 (2011).

3. A. Sen(De) and U. Sen, *Simulating Quantum Dynamics with Entanglement Mean Field Theory*

   J. Phys.: Conf. Ser. **297**, 012018 (2011).

4. H.S. Dhar and A. Sen (De), *Geometry versus Entanglement in Resonating Valence Bond Liquids*,

   J. Phys. A: Math. Theor. **44**, 465302 (2011).

5. R. Prabhu, S. Pradhan, A. Sen(De), and U. Sen, *Disorder overtakes Order in Information Concentration over Quantum Networks*, Phys. Rev. A **84**, 042334 (2011).

Raj Gandhi

1. A. Bhattacharya, R. Gandhi, W. Rodejohann and A. Watanabe, *The Glashow resonance at IceCube: signatures, event rates and pp vs. $p\gamma$ interactions* JCAP **1110**, 017 (2011) [arXiv:1108.3163 [astro-ph.HE]].

2. J. L. Hewett *et al.*, *Fundamental Physics at the Intensity Frontier,'* arXiv:1205.2671 [hep-ex].

3. K. N. Abazaijan *et al.*, *Light Sterile Neutrinos: A White Paper* arXiv:1204.5379 [hep-ph].

4. V. Barger, R. Gandhi, P. Ghoshal, S. Goswami, D. Marfatia, S. Prakash, S. K. Raut and S U. Sankar, *Neutrino mass hierarchy and octant determination with atmospheric neutrinos* arXiv:1203.6012 [hep-ph].

5. S. Choubey *et al.*, *International Design Study for the Neutrino Factory: First Progress Report* IDS-NF-017.

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

7. R. Gandhi and P. Ghoshal, *Atmospheric neutrinos as a probe of eV^2-scale active-sterile oscillations*, arXiv:1108.4360 [hep-ph].

Rajesh Gopakumar

1. M. R. Gaberdiel, R. Gopakumar, T. Hartman and S. Raju, *Partition Functions of Holographic Minimal Models* JHEP **1108**, 077, (2011).

2. A. Castro, R. Gopakumar, M. Gutperle and J. Raeymakers, *Conical Defects in Higher spin Theories* JHEP **1202**, 096, (2012).

Dileep P. Jatkar

1. *BKM superalgebras from counting dyons in N=4 supersymmetric type II compactifications*, S. Govindarajan, D. P. Jatkar and K. Gopala Krishna, Nucl. Phys. B **859**, 143 (2012) [arXiv:1106.1318].

2. *On the Decay of Massive Fields in de Sitter*, D. P. Jatkar, L. Leblond and A. Rajaraman, Phys. Rev. D **85**, 024047 (2012) [arXiv:1107.3513 [hep-th]].

Pinaki Majumdar

1. Viveka Nand Singh and Pinaki Majumdar, *Antiferromagnetic order and Phase Coexistence in a Model of Antisite Disordered Double Perovskites,* Eur Phys. J. B **83**, 147, (2011)

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About the Computer Section

1. Desktops computers for faculty members, post doctoral fellows, research scholars and administrative members of the institute has been upgraded with Intel i7 based machines.
2. Several iMac desktops were purchased and installed.
3. Newer versions of different flavors of Linux operating systems were loaded on the desktops.
4. Webmail server for the Institute was upgraded for the Institute e-mail users.
5. Computing related to conferences were held in the conference computer room.
6. New versions of several applications software were loaded on users' systems, computer centre and conference room systems.
7. All the computer centre NIS client machines were upgraded.
8. Expansion of wireless networking to cover up most of the places of Institute building and library building has been done.
9. A few Laptops for faculty members were purchased.
10. Work order has been released for the upgradation of institute's Mail Server, Name Server, Web Server, and firewall servers.

Current activities and plans

1. Purchased Order for the supply of new iMac desktops for the faculty members of the institute has been released.
2. Purchase Order for the supply of a few high end mono laser printers has been released.
3. Purchase Order for the supply of a few laptops used by students, faulty members and administrative staff has been released.

Library

The Institute's library is one of the best-equipped libraries in the region. Being a research institute, it provides the required support to the academic and research activities. It remained open on all working days between 8 a.m. to 2 a.m. including Saturdays. It also remained open during the Sundays and the Gazzetted holidays from 10 a.m. to 6 p.m. It had added 433 (Four hundred thirty three) books and gifted books 147 in its fold, it increased the total number of books to 20448 (Twenty thousand four hundred forty eight) which includes 927 books as gifted ones. It has also added 478 bound volumes of the journals during the period from 1st April 2011 to 31st March 2012, it has increased bound volumes collection to 35201. The institute's library has a total collection of 55649 (Fifty five thousand six hundred forty nine) of books and bound volumes. The library had subscribed to 225 journals during this period, it includes 110 as online journals.

The physical stock verification has been recently completed with the help of PDT (Portable Data Terminal) for collection of Bar Codes. Since the whole collection is 'Bar Coded' and equipped with 'Tattle Tapes' for security it reflected no loss of titles in either books or journals.

The library is facing a lot of space problem, as we know that "**the library is a growing organism**" the need for space is increasing accordingly, we have already planned for 2.5 folds increase in our present space availability. The construction of the same is also in the full swing which will allow the library space increasing horizontally. Recently we had provided better and latest systems to our users for browsing the library OPAC and related search. We procured one more photocopying machine to provide better photocopying services. We enriched our Building of the Digital Depository of the HRI, which includes the submitted articles, thesis, lectures etc. The library web page has been updated which provides more detailed information about the library such as subscribed databases, archives, library rules, library staff, list of online journals, online link to the Video lectures and other useful links. The emphasis was also given to procure maximum number of journals online. The Institute Library is providing on-line access of the periodicals to our users for 110 (One hundred ten) online titles.

The Library has provided the Web Enabled library catalogue to its users. The library can be termed as completely automated library system, which

includes acquisition, cataloguing, circulation, search modules etc. This on-line catalogue had increased the opportunities of the use of our library resources by the neighboring organizations such as INSDOC, TIFR etc. through the Document Delivery Services (DDS). Normally the library provides the DDS on request through post, at very nominal cost, but requests had also been honoured through email. The library encourages the use of its library by providing library consultation facilities to the research scholars from the neighboring institutes. The Institute had strengthened its library security system made with the implementation of Electro-magnetic Tattle Tapes to reduce the losses. It has been made completely functional.

Construction Activity

1. Construction work of 'Hostel', 'Extension of Institute Building, Library, Computer Centre', 'Engineering building' and 'Community Centre Annexe' at HRI is under progress.
2. Construction of Married Block Apartment at HRI is also under progress.
3. Works related ti "Sewage Treatment Plant" was completed.
4. Additional civil work near substation area was completed.
5. Following miscellaneous works were also carried out during the financial year :
    - Additional light provision in Community Centre back area
    - Providing and fixing of PVC sheet (on the front Verandah in type E-house)