Academic Report – 2016–17

Harish-Chandra Research Institute

Chhatnag Road, Jhunsi, Allahabad 211019

Contents

About The Institute

History

The Harish-Chandra Research Institute is one of the premier research institutes in the country. It is an autonomous institution fully funded by the Department of Atomic Energy (DAE), Government of India. Till 10th Oct 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 acclaimed mathematician, the late Prof Harish-Chandra.

The Institute started with the 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 DAE entered into decisive stage and a review committee was constituted by the DAE to examine the Institute's future. In 1985 Shri N. D. Tiwari, the then Chief Minister of Uttar Pradesh, agreed to provide sufficient land for the Institute and the DAE promised financial support for meeting both the recurring and non-recurring expenditure. In January 1990, about 66 acres of land was acquired in Jhunsi, Allahabad and the Institute came up at this site.

Prof. Shrikhande was followed by Prof. H. S. Mani who took over as the Director in January 1992. With his joining and the shift to the new campus at Jhunsi in 1996, the Institute's activities picked up pace. After a distinguished tenure of about nine years Prof. Mani retired in August 2001 and the charge was taken over by Prof. R. S. Kulkarni. After Prof. Kulkarni's tenure, Prof. Amitava Raychaudhuri was the Director from July 19, 2005 to May 15, 2011. After him Prof. Sumathi Rao officiated as Acting Director till April 28, 2012. Prof. Jayanta Kumar Bhattacharjee was the next Director and continued till April 9, 2017. Prof. Pinaki Majumdar, the current Director, took over on April 10, 2017.

The Institute has a residential campus in Jhunsi, Allahabad with a library, state of the art computational facility and fast internet link to the outside world. There is an active graduate program, a proposal to start a M.Sc program from August 2017, and a large traffic of visiting scientists and students.

Research

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 scientists, post-doctoral fellows and Ph.D. students.

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.

The areas of research in physics are astrophysics, condensed matter physics, quantum information and computing, high energy phenomenology and string theory. In astrophysics, work is done on the cosmic microwave background, large scale structure formation and galaxy evolution. Main areas of activity in condensed matter physics are strongly correlated systems, mesoscopic systems, and the study of 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.

Recognition

Since 1992 the Institute has attracted worldwide attention, as is evident from the recognition received by many of its members. Several members of the Institute have been recognised for their scientific contribution. Prof. Ashoke Sen, Prof. B. Mukhopadhyaya, Prof. Pinaki Majumdar and Prof. Rajesh Gopakumar have been awarded the Shanti Swarup Bhatnagar prize. Prof. Gopakumar also received the Swarnajayanti Fellowship, and the ICTP Prize. The outstanding contribution of Prof. Ashoke Sen has been recognised by a Fellowship of the Royal Society, the award of Padmashri and Padmabhushan and the award of one of the first Fundamental Physics Prize (2012) from the Yuri Milner Foundation. He was the only recipient of the prize from all of Asia. In 2017 the Institute was recognised as being among the top 10 research centers in India by the Nature journal.

Director's Report

The life of a scientific institution consists of research, teaching, and the exchange of ideas. In the few paragraphs below I look at HRI during 2016-17 in the light of these activities.

The exchange of ideas is vital in a fast moving scientific world. In 2016-17 HRI as usual hosted a large number of scientific meetings. These include a Number Theory meet in September 2016, a workshop on Geometry and Analysis in Oct 2016, and a meet on Combinatorics and Number Theory in February 2017. The September meeting was also a celebration of Prof. S. D. Adhikari's 60th birthday. Training programs in mathematics included the Summer Program in Mathematics (SPIM), during summer 2016, and the Annual Foundation School in December 2016.

The physics groups also organised several meetings. These include the Indian Strings Meeting (ISM), hosted at IISER Pune, in December 2016 and a Young-Quantum meet organised by the Quantum Information group. There were also meetings to celebrate the contributions of two senior colleagues - a meeting on Low Dimensional Quantum Systems in February 2017 to celebrate Prof. Sumathi Rao's 60th birthday, and a set of lectures on Fluid Mechanics, Nonlinear Dynamics, and Statistical Physics in March 2017 on the occasion of Prof. J. K. Bhattacharjee's 65th birthday.

In addition to the formal training programs for B.Sc and M.Sc students we held our annual Talent Search examination for school level children in Allahabad, and a week long Vaigyanik Karyashala in hindi to encourage dissemination of science in the vernacular.

Teaching has always been a part of academic life at HRI but we mainly teach a small number of students who go on to do research with us. This year we embark on a more ambitious program. We have laid the groundwork for starting a stand alone M.Sc program in physics from August 2017. This way the benefit of the teaching program will hopefully spread much wider. We have also gone a long way in setting up a teaching laboratory for physics, a novelty in an institution devoted to theory!

Finally research. Fourteen Ph.D students graduated from HRI during 2016-17. Prof. Sumathi Rao was elected a Fellow of the Indian Academy of Sciences, and also honoured as an 'Outstanding Referee' by the American Physical Society. On top of these, HRI was ranked among the top 10 research institutes in India by the Nature magazine. This is a matter of some pride since HRI is tiny, about a tenth in size, compared to other institutions in the list. We should strive to maintain and improve this position.

Pinaki Majumdar

Director

List of Governing Council Members

(2016 -17)

1. Prof. M. S. Raghunathan
   (Chairman)
   503, Atlantis
   Raheja Acropolis-1
   Deonar Pada Road, Deonar,,
   MUMBAI - 400 088

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

3. Mr. R.A. Rajeeev
   Joint Secretary (Finance) DAE
   Govt. of India,
   Chhatrapati Shivaji Maharaj Marg,
   MUMBAI - 400 001

4. Smt. Chitra Ramachandran
   Joint Secretary (R & D)
   DAE, Govt. of India,
   Anushakti Bhavan,
   Ch. Shivaji Maharaj Marg
   Mumbai - 400 001

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

6. Prof. S.M. Chitre
   Chair, Academic Board
   University of Mumbai
   Department of Atomic Energy
   Centre for Excellence in Basic Sciences(UM-DAE-CBS)
   Health Centre Building
   University of Mumbai
   Kalina Campus,
   Mumbai-400 098

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

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

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

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

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

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

ACADEMIC STAFF

Faculty Members (Mathematics)

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

Faculty Members (Physics)

1. Dr. Basu, Anirban
2. Dr. Choubey, Sandhya
3. Dr. Das, Tapas Kumar
4. Dr. Datta, Aseshkrishna
5. Prof. Gandhi, Raj
6. Prof. Gopakumar, Rajesh (on lien)
7. Prof. Jatkar, Dileep
8. Dr. Maharana, Anshuman
9. Prof. Majumdar, Pinaki
10. Prof. Mukhopadhyaya, B.
11. Prof. Naik, S.
12. Dr. Pai, G.Venketeswara

13. Dr. Pareek, T. P.
14. Prof. Pati, Arun Kumar
15. Dr. Rai, Santosh Kumar
16. Prof. Rao, Sumathi
17. Prof. Sen, Ashoke
18. Prof. Sen, Prasenjit
19. Dr. Sen, Ujjwal
20. Dr. Sen(De), Aditi

Administrative Staff

1. Shri Ravindra Singh [Registrar]
2. Shri Rajkumar Gulati [Accounts Officer]
3. Shri Manish Sharma [Scientific Officer 'D']
4. Shri Amit Roy [Internal-Audit-cum Administrative officer]
5. Shri Sanjai Verma [Systems Manager]
6. Shri A.K. Srivastava [SO (SB) (Electrical)]
7. Shri V.K. Srivastava [SO (SB) (Civil)]
8. Shri Jagannath Yadav [Accountant]
9. Shri R.P. Sharma [Manager Guest House]
10. Ms. Archana Tandon [Office Superintendent]
11. Ms. Anju Verma [Scientific Assistant]
12. Shri U.K. Dwivedi [Cashier]
13. Shri D. Malhotra [Upper Division Clerk]
14. Shri K.K. Srivastava [Upper Division Clerk]
15. Shri Yashpal Singh [Stenographer]
16. Ms. Sumitra [Upper Division Clerk]
17. Ms. Seema Agarwal [Receptionist]
18. Mr. Om Kumar Karn (on lien) [Junior Hindi Translator]
19. Shri Surendra Yadav [Store/Purchase Officer]
20. Shri Dharampal Sharma [Jr. Lib. Assistant]
21. Shri Sanjeev Nagar [Hindi Typist]
22. Shri D.N. Dubey [Bearer (Canteen Cadre)]
23. Shri Kamlesh Thakur [Bearer (Canteen Cadre)]
24. Shri R.K. Dixit [Peon/Watchman]
25. Shri Kamta Prasad [Peon/Watchman]
26. Shri Rajesh Kumar [Sweeper]
27. Shri Munna Lal [Gardener]

Visiting Fellow

Mathematics

1. Dr. Arunachalam, Umamaheswaran
2. Dr. Bera, Sayani
3. Dr. Choudhury, Snigdha Bharati
4. Dr. Datt, Gopal
5. Dr. Ganguli, Saibal
6. Dr. Hoque, Azizul
7. Dr. Kitture, Rahul Dattatray
8. Dr. Kumari, Rani
9. Dr. Kushwaha, Seema
10. Dr. Manna, Ramesh
11. Dr. Mistri, Raj Kumar
12. Dr. Nayak, Saudamini
13. Dr. Podder, Shubhankar
14. Dr. Pujahari, Sudhir Kumar
15. Dr. Raja, Rameez
16. Dr. Ram, Samrith
17. Dr. Ransingh, Biswajit
18. Dr. Raundal, Hitesh Ramesh
19. Dr. Raut, Sudhansu Shekhar
20. Dr. Trivedi, Shailesh
21. Dr. Upadhyay, Abhitosh
22. Dr. Vanlalngaia, Ramdinmawia

Physics

1. Dr. Bhattacharya, Samyadeb
2. Dr. Biswas, Anirban
3. Dr. Chakraborty, Indrani
4. Dr. Das, Debmalya
5. Dr. Dutta, Debajyoti
6. Dr. Gupta, Manish Kumar
7. Dr. Gupta, Manjari
8. Dr. Islam, Safiqul
9. Dr. Jeon, Imtak
10. Dr. Kumar, Dushyant
11. Dr. Kundu, Nilay
12. Dr. Mandal, Tanmoy
13. Dr. Mishra, Priti
14. Dr. Mohan, Priyanka
15. Dr. Mondal, Subhodeep
16. Dr. Nii, Keita
17. Dr. Sadhukhan, Abhishake
18. Dr. Sazim, S.K.
19. Dr. Singh, Chabungbam Satyananda
20. Dr. Singh, Dheeraj Kumar
21. Dr. Singh, S. Nilakash
22. Dr. Suryanarayana, Venkatta

Visiting Scientist

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

Research Scholar

Mathematics

1. Mr. Banerjee, Soumyarup
2. Mr. Chattopadhyay, Jaitra
3. Mr. Das, Mithun Kumar
4. Mr. Das, Pradeep
5. Ms. Hatui, Sumana
6. Mr. Karmakar, Debasish
7. Mr. Kaushik, Rahul
8. Mr. Kumar, Arvind
9. Mr. Kumar, Veekesh
10. Mr. Maity, Arup Kumar
11. Mr. Mallesham, K
12. Mr. Manikandan, S.
13. Mr. Mehar, Nabin Kumar
14. Mr. Naik, Tushar Kanta
15. Mr. Pandey, Manish Kumar
16. Mr. Patil, Bhuwanesh Rao
17. Mr. Pramod, E.
18. Ms. Roy, Bidisha
19. Mr. Sahoo, Gopinath
20. Mr. Sarkar, Subha
21. Ms. Sharma, Ritika
22. Mr. Singh, Anup Kumar
23. Mr. Singh, Anoop
24. Mr. Singh, Rahul Kumar
25. Mr. Vaishya, Lalit

Physics

1. Mr. Alam, Khorsed
2. Mr. Bakshi, Sankha Subhra
3. Mr. Banerjee, Aditya
4. Mr. Basak, Nirnoy
5. Mr. Beuria, Jyotiranjan
6. Mr. Bhattacharya, Ritabrata
7. Mr. Bhattacharya, Sauri
8. Mr. Chakrabarti, Subhroneel
9. Mr. Chakrabarty, Nabarun
10. Mr. Chanda, Titas
11. Mr. Das, Kasinath
12. Ms. Das, Sreetama
13. Mr. Das, Tamoghna
14. Mr. Datta, Satadal
15. Mr. De, Suman Jyoti
16. Ms. Deshpande, Rhucha
17. Ms. Dey, Atri
18. Mr. Dutta, Arijit
19. Ms. Dutta, Juhi
20. Mr. Dwivedi, Siddharth
21. Mr. Ghosh, Avirup
22. Mr. Goswami, Mrityunjay
23. Mr. Gupta, Aritra
24. Mr. Haldar, Stav
25. Mr. Joshi, Abhishek
26. Mr. Kadge, Samrat Suresh
27. Mr. Kar, Arpan
28. Mr. Kashyap, Sitender Pratap

29. Mr. Khan, Sarif
30. Mr. Khanna, Udit
31. Mr. Kumar, Abhass
32. Mr. Kumar, Asutosh
33. Mr. Mahanta, Ratul
34. Ms. Maity, Ajanta
35. Mr. Maity , Susovan
36. Mr. Mohan, Brij
37. Mr. Mukherjee, Dibya Kanti
38. Mr. Mukhopadhyay, Chiranjib
39. Mr. Pramanik, Dipyaman
40. Mr. Roy, Samiran
41. Mr. Roy, Saptarshi
42. Mr. Roy, Sudipto Singha
43. Ms. Roy, Tanaya
44. Mr. Roychoudhury, Shouvik
45. Mr. Sadhukhan, Debasis
46. Mr. Sahoo, Biswajit
47. Ms. Saxena, Ruchi
48. Mr. Sehrawat, Sandeep Kumar
49. Ms. Sen, Arpita
50. Md. Shaikh, Arif
51. Mr. Sharma, Gautam
52. Mr. Singh, Uttam
53. Mr. Sohail
54. Mr. Srivastava, Chirag
55. Mr. Swain, Nyayabanta
56. Mr. Tiwari, Deepak
57. Mr. Tripathi, Krashna Mohan
58. Mr. Verma, Mritunjay Kumar

Academic Report - Mathematics

Sukumar Das Adhikari

Research Summary:

Continuing work on problems related to existence of monochromatic solutions of certain equations for finite colorings of integers and some extremal problems in combinatorics. In a joint work with Anirban Mukhopadhyay and M. Ram Murty, a proof of the result of Iosevich and Rudnev on the analog of the Erdős-Falconer distance problem has been given in the case of a finite field of characteristic p, where p is an odd prime, without using estimates for Kloosterman sums. The case of characteristic two has also been addressed.

Publications:

1. S. D. Adhikari, L. Boza, S. Eliahou, J. Marín, M. Revuelta and M. Sanz, *On the finiteness of some n-color Rado Numbers*, Discrete Math. **340**, 39-45 (2017).
2. S. D. Adhikari, Anirban Mukhopadhyay and M. Ram Murty, *The analog of the Erdős distance problem in finite fields*, Int. J. Number Theory, (to appear).

Conference/Workshops Attended:

1. *The Mathematics of JirI Matousek*, Prague, Czech Republic, July 2016.
2. *IST in Algebraic Number Theory*, Pune, October 2016.
3. *AMS-TIMC conference*, Banaras Hindu University, December, 2016.

Visits to other Institutes:

1. NISER, Bhubaneswar, June 2016.
2. ULCO, Calais, France, July 2016 and March 2017.
3. Departamento de Matemática Aplicada I, Universidad de Sevilla, Spain, October 2016.
4. IIT Delhi, December 2016.
5. IIIT Delhi, December 2016.
6. RKMVU, Belur, January, 2017.

Invited Lectures/Seminars:

1. Gave a course in Combinatorics at TPM 2016 at NISER, Bhubaneswar, in June 2016.

2. Gave an invited talk at 'RTRT 16: Ramsey Theory and related topics',

   held at Departamento de Matemática Aplicada I, Universidad de Sevilla, Spain, October 2016.

Punita Batra

Research Summary:

Higher rank toroidal Lie superalgebras can be realized in terms of finite number of copies of affine Lie superalgebras in type A and two copies of affine Lie superalgebras in type D. So Serre type relations for higher rank toroidal Lie superalgebras can be described in terms of Serre type relations of affine Lie superalgebras. We are also trying to find the Serre type relations for type B and C toroidal Lie superalgebras. This is a joint work with H. Yamane.

Another work is in progress where i am trying to find out the central operators for $\widetilde{gl_N} \otimes A$, where $\widetilde{gl_N}$ is an affine Kac-Moody Lie algebra for gl_N and A is a finitely generated commutative, associative algebra with unit.

Publications:

1. S.Eswara Rao and Punita Batra, *Classification of irreducible integrable highest weight modules for current Kac-Moody algebras,* Journal of Algebra and its Applications, Number 7, Volume 16, (2017).
2. Punita Batra and Hiroyuki Yamane, *Centers of Generalized quantum groups,* To appear in Journal of Pure and Applied Algebra, available online June 9, 2017.
3. S. Eswara Rao and Punita Batra, *On integrable modules for the twisted full toroidal Lie algebra,* To appear in Journal of Lie Theory.

Preprints:

1. (With Hiroyuki Yamane) A Serre type presentation for higher rank toroidal Lie superalgebras, In preparation.

Conference/Workshops Attended:

1. "International workshop and conference on Infinite dimensional Lie superalgebras and their representations" at IPM-Isfahan, Isfahan, Iran, May 25-29, 2016.
2. " International Conference on Algebra and its Applications" at Aligarh Muslim University, Aligarh, Nov 12-14, 2016.

Visits to other Institutes:

1. IPM-Isfahan, Isfahan, Iran during May 25-29, 2016.
2. Aligarh Muslim University, Aligarh during Nov 12-14, 2016.

Invited Lectures/Seminars:

1. *Integrable modules for the twisted full toroidal Lie algebras* , International Workshop and conference on Infinite dimensional Lie superalgebras and their representations , IPM-Isfahan, Iran, May 26, 2016.

2. *Representations of the twisted full toroidal Lie algebras* , International Conference on Algebra and its Applications, AMU, Aligarh, Nov 13,2016.

Other Activities:

1. Gave two lectures in the Rajbhasha scientific workshop at HRI in June 2016.

2. Organiser of SPIM(Summer Programme in Mathematics) 2016.

3. Gave six lectures on " Field Theory" in Summer Programme in Mathematics(SPIM) at HRI in June, 2016.

4. Gave a talk in Sen-sessions(Conference to celebrate Ashok Sen's 60th Birthday) in August 2016.

5. Gave a second year graduate course "Lie Algebras and Representation Theory" during August-December 2016.

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

Kalyan Chakraborty

Research Summary:

Extended our previous study of the asymptotic behaviour of the Riesz sum associated to the classical cusp forms of level 1 to higher levels. This is done by using the properties of the corresponding Rankin-Selberg L-functions and the symmetric square L-functions. The main term of this estimation gives information about the non-trivial zeros of the Dirichlet L-functions generalising the previous main term which was giving information about the non-trivial zeros of the Riemann zeta-functions. We are continuing this study for other automorphic forms and also to higher powers.

Class numbers of number fields is a fascinating object and not much information is available regarding how it to be explicitly calculated or other arithmetic nature like divisibility or non-divisibility etc. Completed study of divisibility and non-divisibility of class numbers of some interesting families of real and imaginary quadratic fields. Also, studied the same problem for maximal real subfields of certain cyclotomic fields towards the qualitative direction. We are working towards more results towards non-divisibility results as only few results are available in this direction. There are well known conjectures and questions in the maximal real set up and we are working towards getting information towards this direction too.

GNFS is an well known method to factorize a big number which is an integral part of security. Under a project sanctioned by DRDO, Govt. of india, I am involved along with SAG to develop a couple of modules of GNFS.

Publications:

1. Kalyan Chakraborty, Shigeru Kanemitsu and Takako Kuzumaki, *A Quick Introduction To Complex Analysis,* World Scientific, Singapore, (2016).

2. K. Chakraborty, I. Kátai and B. M. Phong, *Additive functions on the greedy and lazy Fibonacci expansions,* J. Integer Seq. **19** Issue 4, 16.4.5, 12 pp. 11B39 (11A25 11A67) (2016).

3. Kalyan Chakraborty, Shigeru Kanemitsu and Bibekananda Maji, *Modular-type relations associated to the Rankin-Selberg L-functions,* The Ramanujan Journal **42**, Issue. 2, 285–299, (Feb. 2017).

4. Kalyan Chakraborty, Jorge Jimenez Urroz and Francesco Pappalardi, *Pairs of integers which are mutually squares,* Sci. China Math., 1–14, (2017) DOI : 10.1007/s.1. 1425-010-0343-1.

5. B. Maji, D. Banerjee, K. Chakraborty and S. Kanemitsu, *Abel-Tauber process and asymptotic formulas,* Kyushu J. of Mathematics, (Accepted for Publication).

6. B. Maji, A. Juyal, K. Chakraborty and S. D. Kumar, *Asymptotic expansion of a Lambert series,* International Journal of Number Theory, (Accepted for Publication).

Preprints:

1. K. Chakraborty, S. Kanemitsu and A. Laurinčikas, *Complex powers of L-functions and integers without large prime factors.*
2. Azizul Hoque and Kalyan Chakraborty, *Divisibility of class number of certain families of quadratic fields.*
3. Azizul Hoque and Kalyan Chakraborty, *Pell-type equations and class number of the maximal real subfield of a cyclotomic field.*
4. K. Chakraborty, A. Hoque, Y. Kishi and P.P. Pandey, *Divisibility of the class numbers of imaginary quadratic fields.*
5. S. Banerjee, A. Hoque and K. Chakraborty, *On the product of two Dedekind zeta functions.*
6. Kalyan Chakraborty, Azizul Hoque and Raj Kumar Mistri, *Imaginary quadratic fields with class number not divisible by a given integer.*

Conference/Workshops Attended:

1. *ICFIDCCA-2016*, India, Jaipur, August, 2016.
2. *ICSFA - 2016*, India, September, 2016.
3. *Two days - Number Theory Meet*, HRI, India, September, 2016.
4. *Combinatorics and Number Theory Meet*, HRI, India, February, 2017.
5. *ICNTASF-2017*, China, March, 2017.

Visits to other Institutes:

1. Anand International College of Eng., Jaipur, India, August, 2016.
2. Kinki University, Fukuoka, Japan, November, 2016.
3. North West University, Xian, China, March, 2017.
4. Hong Kong University, Hong kong, March, 2017.
5. Shaanxi Xueqian Normal University, Xian, China, March, 2017.
6. Tribhuvan University, Kathmandu, Nepal, July, 2016.
7. JMI- Central University, Delhi, India, November, 2016.
8. Pt. Ravi Shankar Shukla University, Raipur, India, December, 2016.
9. NIT-Sikkim, Ravangla, Sikkim, October, 2016.
10. SAG-DRDO, Delhi, India, February, 2017.

Invited Lectures/Seminars:

1. *Quadratic reciprocity and Riemann's non-differentiable function*, ICFIDCCA-2016, Anand International College of Engn., Jaipur, August, 2016.
2. *Beta functions - Some Applications*, ICSFA-2016, JMI - Central University, Delhi, September, 2016.
3. *Class numbers of maximal real subfields of certain cyclotomic fields*, Combinatorics and NumberTheory Meet, HRI, Allahabad, February, 2017.
4. *Class numbers of maximal real subfields of certain cyclotomic fields*, ICNTASF - 2017, Shangsui Normal University, Shangsui, China, March, 2017.
5. *Prime numbers and more..* Popular lecture series, Shaanxi Xueqian Normal University, Xian, March, 2017.
6. *Class numbers of maximal real subfields of certain cyclotomic fields*, Weekly Number Theory Seminar, Hong Kong University, Hong Kong, March, 2017.

Other Activities:

1. Inspire Mentoring, June, September, December, 2016.
2. IMU Project on Galois Theory (5 Years), July, 2016.
3. Referring, Reviewing, Student Mentoring, Throughout the year.

Chandan Singh Dalawat

Research Summary:

A finite separable extension E of a field K is called solvable if the group $\mathrm{Gal}(\hat{E}|K)$ of K-automorphisms of its galoisian closure $\hat{E}$ over K is solvable. It is called a primitive extension if $E \neq K$ and if the only extensions of K in E are K and E. We have parametrised the set of primitive solvable extensions of an arbitrary field K.

When K is a local field with finite residue field, every finite separable extension of K is solvable. The only interesting primitive extensions of K are those of degree p^n (for some $n > 0$), where p is the residual characteristic of K. For every n, we specify a certain explicit finite tamely ramified split galoisian extension L_n of K and show that the set of primitive extensions E of K of degree p^n is in natural bijection with the set of irreducible representations of degree n of the group $\mathrm{Gal}(L_n|K)$ in the $\mathbf{F}_p$-space $L_n^\times/L_n^{\times p}$ in characteristic 0 or $L_n^+/\wp(L_n^+)$ in characteristic p, where $\wp(x) = x^p - x$.

We show how to determine the group $\mathrm{Gal}(\hat{E}|K)$, where $\hat{E}$ is the galoisian closure of E over K. We also show how to determine the differental exponent of E in terms of the filtration on $L_n^\times/L_n^{\times p}$ or $L_n^+/\wp(L_n^+)$.

For every finite tamely ramified split galoisian extension L of K, we determine the stucture of the filtered $\mathbf{F}_p$-space $L^\times/L^{\times p}$ or $L_n^+/\wp(L_n^+)$ as a module over the group $\mathrm{Gal}(L|K)$.

We show how the local reciprocity isomorphism for the maximal abelian extension of exponent p of a local field K with finite residue field of characteristic p is related to the natural filtration on the additive and mulitiplicative groups of K.

In short, we have parametrised the set of primitive solvable extensions of an arbitrary field and worked it out explicitly in the case of a local field with finite residue field. We have also shown that the local reciprocity isomorphism satisfies a certain orthogonality relation.

Publications:

1. Chandan Singh Dalawat & Jung-Jo Lee, *Tame ramification and group cohomology*, Journal of the Ramanujan Mathematical Society **32**(1), 51–74, 2017.

Preprints:

1. Chandan Singh Dalawat, *Solvable primitive extensions*, arXiv:1608.04673

2. Chandan Singh Dalawat, $\mathbf{F}_p$*-representations over* p*-fields*, arXiv:1608.04181

3. Chandan Singh Dalawat, *Little galoisian modules*, arXiv:1608.04182

4. Chandan Singh Dalawat, *Wildly primitive extensions*, arXiv:1608.04183

5. Chandan Singh Dalawat, *Reciprocity and orthogonality*, arXiv:1609.01160

Invited Lectures/Seminars:

1. *Solvable primitive extensions*, Indian Institute of Technology, Kanpur, 30 December 2016 ; Indian Institute of Technology, Delhi, 30 January 2017 ; Indian Institute of Technology, Gandhinagar, 3 March 2017 ; Shiv Nadar University, 20 March 2017.
2. *Solving equations by radicals, from Galois to last year*, Institute of Infrastructure Technology Research and Management, Ahmedabad, 2 March 2017.

Other Activities

Examined the doctoral thesis of a candidate from Università di Pisa and a candidate from IIT Delhi, and acted as the external examiner for the latter. Gave a set of two lectures in the outreach programme. Mentored a student from NISER Bhuvaneshwar and one from IISER Poona. Gave a set of two lectures in an Inspire Camp of the DST. Refereed papers for international journals.

Umesh Kumar Vanktesh Dubey

Research Summary:

Tensor triangular geometry is a study of tensor triangulated categories using algebro-geometric methods. The role of Zariski topology from algebraic geometry is played by Bousfield localizations. Similarly Balmer observed that the role of étale morphism is played by seprable monads via Eilenber-Moore construction. Along the way Balmer asked for an existence of triangulated structure on the Eilenber-Moore category associated to an exact monad. We partially answered this question of Balmer using the notion of enhacement of triangulated categories and DG monads. We also extended some results of Balmer and studied some examples like twisted and equivariant derived categories. This is a joint work with Vivek M. Mallick.

The classification of thick subcateogories of a singularity category was achieved by Stevenson for local complete intersection rings. In a joint work in progress with Sarang Sane we are trying to extend these results to the case of graded singularity categories introduced and studied by Orlov.

We studied a functorial construction of moduli of equivariant pure sheaves with Sanjay Amrutiya. In a joint work in progress with him we are extending these results to get the similar functorial construction for the moduli space of parabolic bundles via Biswas-Seshadri correspondence and Kronecker-McKay quivers.

Preprints:

1. Umesh V. Dubey and Vivek M. Mallick, *On differential graded Eilenberg - Moore construction,* (communicated).
2. Umesh V. Dubey and Sarang Sane, *Classification of thick subcategories of some graded singularity categories,*(work in progress).
3. Umesh V. Dubey and Sanjay Amrutiya, *On functorial construction of moduli space of parabolic bundles,* (work in progress).

Conference/Workshops Attended:

1. *National conference on Commutative Algerba and Algebraic Geometry*, IISER Mohali, INDIA, 11 - 15 October, 2016.
2. *INSPIRE faculty Monitoring-cum-interaction Meet*, Goa University, INDIA, 27 January, 2017.

Visits to other Institutes:

1. Indian Institute of Science Education and Research, Pune, INDIA, 21 - 26 November, 2016.
2. Indian Institute of Technology, Gandhinagar, INDIA, 19 - 25 February, 2017.

Invited Lectures/Seminars:

1. *Thick subcategories of singularity category*, conference talk in CAAG, Indian Institute of Science Education and Research, Mohali, October, 2016.

2. *Tensor triangular Chow group*, Maths seminar, Indian Institute of Science Education and Research, Pune, November, 2016.

Other Activities:

1. Six lectures and two tutorials on Topology, AFS-I, Harish-Chandra Reseach Institute, December, 2016.

2. Three lectures and one tutorial on Complex Analysis, AFS-I, Harish-Chandra Reseach Institute, December, 2016.

3. Poster presentation at INSPIRE faculty Monitoring-cum-interaction Meet, January, 2017.

4. Seminar series on Goemetric Invariant Theory, Harish-Chandra Reseach Institute, January - April, 2017.

Manoj Kumar

Research Summary:

Let G be a central product of its normal subgroups H and K with $A = H \cap K$, and $H^2(G, D)$ the second cohomology group of G with coefficients in D, where D is a divisible abelian group regarded as a trivial G-module. Let $Z := \gamma_2(H) \cap \gamma_2(K)$, where $\gamma_2(X)$ denotes the commutator subgroup of a group X. We first reduce the study to the case when $Z = 1$ by proving: For any subgroup B of G such that $B \leq Z$, we have

$$H^2(G, D) \cong H^2(G/B, D)/N,$$

where $N \cong Hom(B, D)$. Then we prove: Let $L \cong Hom\big((A \cap H')/Z, D\big)$, $M \cong Hom\big((A \cap K')/Z, D\big)$ and $N \cong Hom(Z, D)$. Then (i) $\big(H^2(H/A, D)/L \oplus H^2(K/A, D)/M\big)/N \oplus Hom(H/A \otimes K/A, D)$ embeds in $H^2(G, D)$ and (ii) $H^2(G, D)$ embeds in $\big(H^2(H/Z, D) \oplus H^2(K/Z, D)\big)/N \oplus Hom(H \otimes K, D)$.
In particular, when $D = \mathcal{C}^\times$, the multiplicative group of units of complex numbers, then we get the same results for Schur multiplier of G.

Publications:

1. Manoj K. Yadav, *Central quotient versus commutator subgroup of groups,* Algebra and its Applications, Springer Proceedings in Mathematics and Statistics **174**, 183 - 194, (2016).

Preprints:

1. Sumana Hatui, L. R. Vermani and Manoj K. Yadav, *Schur multiplier of central product of groups, Preprint.*

2. Rahul D. Kitture and Manoj K. Yadav, *Finite groups with abelian automorphism groups - A Survey,* (in preparation).

Conference/Workshops Attended:

1. *Group Theory and Computational Methods*, India, November, 2016.

2. *Discussion Meeting on Topology and Groups*, India, October, 2016.

Visits to other Institutes:

1. University of Florence, Florence, Italy, March, 2017

2. TIFR, Mumbai, India, December, 2016.

3. IISER, Pune, India, October, 2016.

4. IISER, Mohali, India, June, 2016.

5. IISER, Mohali, India, March, 2016.

Invited Lectures/Seminars:

1. *Finite p-groups with exactly two conjugacy class sizes*, Algebra Seminar, University of Florence, Florence, March, 2017.
2. *Finite p-groups with exactly two conjugacy class sizes*, Discussion Meeting on Topology and Groups, IISER, Mohali, October, 2016.
3. *Finite p-groups with exactly two conjugacy class sizes*, Algebra Seminar, IISER, Pune, October, 2016.

Other Activities:

1. Taught a semester course 'Algebra - I' at HRI, August - December, 2016.
2. Organized an ICTS activity 'Group Theory and Computational Methods', November 05-14, 2016 at ICTS, Bangalore.
3. Refereed papers for many national and international journals.

Gyan Prakash

Research Summary:

We worked on a problem of A. Sárközy which asks for chromatic versions of the classical theorems of Lagrange and Vinogradov which state that every natural number is a sum of four squares and respectively that every sufficiently large natural number is the sum of at most four prime numbers. With D.S. Ramana and O. Ramaré we completed our work, reported as a preprint last year, and obtained a close to optimal answer to Sárközy's problem for the squares. The first listed publication describes this work. Together with K. Mallesham and D. S. Ramana, we have sought to obtain an analogous result for squares of prime numbers. Our results are given in preprint listed below, which is due to be submitted for publication.

In a work in progress with François Hennecart, we are studying the following problem. Given a natural number n, how thin a subset A of the integers exist which satisfy the property that every sufficiently large natural number can be expressed as $a_1 \dots a_n + a_{n+1}$ with $a_i \in A$ for every i. We have got a nearly optimal answer when $n \geq 3$ and the work is in progress for $n = 2$.

Publications:

1. Gyan Prakash, D.S. Ramana and O. Ramaré *Monochromatic Sums of Squares*, accepted in Math. Zeitshrift.

Preprints:

1. K. Mallesham, Gyan Prakash and D.S. Ramana *Monochromatic Sums of Prime Squares*, (in preparation).

Conference/Workshops Attended:

1. *International Conference on Number Theory*, KSOM, Kozhikode, January 2017.

Invited Lectures/Seminars

1. *Thin subsets with product set as an additive complement*, Combinatorics and Number theory meet, HRI, Allahabad, February, 2017

2. *Structure of sets with small doubling*, KSOM Lecture series in mathematics, KSOM, Kozhikode, November 2016.

Other Activities:

1. Served as an organiser of an *International Conference on Number Theory*, KSOM, Kozhikode, January 2017.

Raghavendra Nyshadham

Research Summary:

I have been working on the moduli theory of representations of quivers with my students.

Preprints:

1. Pradeep Das, S. Manikandan, and N. Raghavendra, *Holomorphic aspects of moduli of representations of quivers*, submitted.

Other Activities:

1. Coorganised the Annual Foundation School (AFS) I, funded by the National Centre for Mathematics, from 5th to 31st December, 2016, at HRI, and gave six lectures on topology in the school.

D Surya Ramana

Research Summary:

My research continued to focus on the problem of A. Sárközy which asks for chromatic versions of the well-known facts that every natural number is a sum of four squares and likewise, that every sufficiently large natural number is the sum of no more than four prime numbers. With Gyan Prakash and O. Ramaré we completed our work, reported in preprint form last year, giving a nearly optimal answer to Sárközy's problem for the squares. This is the content of the first publication listed below. With K. Mallesham and Gyan Prakash, we have sought to obtain analogous results for squares of prime numbers. Our results are available in the second preprint listed below, which is being finalised for publication. In addition to pursuing other threads within the theme of Sárközy's problems, we have studied the following problem, considered Sárközy and P. Erdös : let $\mathcal{A}$ be a subset of the natural numbers with the property that z divides $x + y$ with x, y, z in $\mathcal{A}$ implies either that $x \leq z$ or that $y \leq z$. Also, suppose that the elements of $\mathcal{A}$ are mutually coprime. Then is it true that $|A(X)| \ll X^{\frac{1}{2}+\epsilon}$? Progress in this question would be very interesting within the theory of the large sieve inequalities.

Publications:

1. G. Prakash, D.S. Ramana, O. Ramaré *Monochromatic Sums of Squares,* Math. Z..
2. J. Cilleruelo, D.S. Ramana and O. Ramaré *Quotient and product sets of thin subsets of the positive integers,* Proceedings of the Steklov Institute of Mathematics, Vol. 296, No. 1, pp. 52-64, 2017.

Preprints:

1. D.S. Ramana and O. Ramaré, *Variant of the Truncated Perron's Formula and Primitive Roots*, Submitted.
2. K. Mallesham, Gyan Prakash and D.S. Ramana *Monochromatic Sums of Prime Squares.* pp. 22.

Conference/Workshops Attended:

1. *International Conference on Number Theory*, KSOM, Kozhikode, January 2017.

Visits to other Institutes:

1. University of Aix-Marseille, France, November, 2016.

Other Activities:

1. Taught in the AFS II programme at HRI, December, 2016.
2. Served as Convenor of Graduate Committee in Mathematics, Library Committee and as member of the Local Works Committee.

Ratnakumar Peetta Kandy

Research Summary:

During the last one year, I was mostly working on the ongoing project on the study of local smoothing of Fourier integral operators with my Ph. D. Student Ramesh Manna. We have extended the previosly known result of Mockenhaupt, Sogge and Seeger to more general class of Fourier integral operators with amplitude functions that depends on the space time variable also. Using a duality argument we provide a simpler proof, and our local smoothing estimate requires only minor decay condition on a few derivatives of the amplitude function, with respect to the space time variables. This work is now complete and will be submitted soon.

I am also working on Hardy-Sobolev inequality on the Heisenberg group, jointly with Adimurthi at TIFR CAM, Bangalore. This work is in progress.

Publications:

1. Adimurthi, P.K. Ratnakumar and Vijay Kumar Sohani, *A HardySobolev inequality for the twisted Laplacian,* Proceedings of the Royal Society of Edinburgh Section A: Mathematics **Vol 147**, 1-23, (2017).

Preprints:

1. Ramesh Manna and Ratnakumar P.K., *On local smoothing of fourier integral operators in two dimensions.*

Conference/Workshops Attended:

1. *Recent Trends in Mathematical Analysis and Its Applications*, Banares Hindu University, India, February, 2017.

Visits to other Institutes:

1. TIFR Centre for Applicable Mathematics, Bangalore, India, December, 2016.

2. Banares Hindu University, Varanasi, India, February 2017.

Invited Lectures/Seminars:

1. *Functions operating on modulation spaces and nonlinear dispersive equations*, Recent Trends in Mathematical Analysis and Its Applications, Banares Hindu University, Varanasi, February, 2017.

Other Activities:

1. A workshop on "Geometry and Analysis on CR Manifolds" was organised at HRI in October, 2017.

2. Served in HRI Mathematics PDF committe, as convener.

Hemangi Madhusudan Shah

Research Summary:

During 2016-2017 I worked on various projects. The list and a brief summary of various research projects is as follows: 1) Asymptotically Harmonic Manifolds of dimension 4 2) Pinching theorems related to critical exponent 3) Geometry of asymptoticallly harmonic manifolds with minimal horospheres. 4) Almost maximal volume entropy.

I worked on the project: "Asymptotically Harmonic Manifolds of dimension 4". We show that : Asymptotically harmonic and Einstein manifolds of dimension 4 are symmetric spaces in dimension 4. More precisely, we show that Asymptotically harmonic and Einstein manifolds of dimension 4 is either RH^4 or CH^2.

I studied Cheeger -Colding theory towards my upcoming paper on " Pinching theorems related to critical exponent". [1] Cheeger J., Degeneration of Riemannian metrics under Ricci curvature bounds, Suola Normale Superiore, Pisa, 2001, 77 pgs. [2] Cheeger J.; Colding T., Lower bounds on Ricci curvature and the almost rigidity of warped products, Ann. Math. (2) 144 (1996), 1, 189-237.
The brief summary of results which will be proved in the paper: Pinching theorems related to critical exponent" :
We show that there exist a positive constant $\varepsilon(n, D)$ such that for any compact Riemannian manifold (M^n, g) of dimension $n \geq 3$, with Ricci $(g) \geq -(n-1)g$, diam$(M^n, g) \leq D$, the volume entropy $h(g) \geq n-1-\varepsilon$, for some $\varepsilon \leq \varepsilon(n, D)$ carries a hyperbolic manifold g_0. Moreover, the Gromov-Hausdorff distance $d_{GH}((M^n, g), (M^n, g_0)) \leq \alpha(\varepsilon)$, where $\alpha(\varepsilon)$ tends to 0 when ε tends to 0. This result was proved by the first author, when a compact Riemannian manifold (M^n, g) of dimension $n \geq 4$, with Ricci $(g) \geq -(n-1)g$, $h(g) \geq n-1-\varepsilon$ and vol $(M^n, g) \leq V$ also has sectional curvature $K_g \leq -a^2 < 0$. In this case, there exist a positive constant $\varepsilon(n, a, V)$, so that the conclusion as above holds.

I also worked on various research projects related to harmonic and asymptotic harmonic manifolds. Towards this recently I proved that: Asymptotically harmonic manifolds with minimal horospheres are flat. More precisely, it is proved that:
(M^n, g) be a complete Riemannian manifold without conjugate points. In this paper, we show that if M is also simply connected, then M is flat, provided that M is also asymptotically harmonic manifold with minimal horospheres (AHM). The (first order) flatness of M is shown by using the strongest criterion: $\{e_i\}$ be an orthonormal basis of T_pM and $\{b_{e_i}\}$ be the corresponding Busemann functions on M. Then,
(1) The vector space $V = span\{b_v | v \in T_pM\}$ is finite dimensional and dim $V =$ dim $M = n$.
(2) $\{\nabla b_{e_i}(p)\}$ is a global parallel orthonormal basis of T_pM for any $p \in M$. Thus, M is a parallizable manifold.
And
(3) $F : M \to R^n$ defined by $F(x) = (b_{e_1}(x), b_{e_2}(x), \cdots, b_{e_n}(x))$, is an isometry and therefore, M is flat.
Consequently, AH manifolds can have either polynomial or exponential volume growth, generalizing the corresponding result of Nikolayevesky for harmonic manifolds. In case of harmonic manifold with minimal horospheres (HM), the (second order) flatness was proved in author's joint paper by showing that $span\{b_v^2 | v \in T_pM\}$ is finite

dimensional. We conclude that, the results obtained in this paper are the strongest and wider in comparison to harmonic manifolds, which are known to be AH.

I also worked on joint project related to "Almost maximal volume entropy". More precisely, we show that:
We prove the existence of manifolds with almost maximal volume entropy which are not hyperbolic.

Publications:

1. Hemangi Shah, *3-dimensional asymptotically harmonic manifolds with minimal horospheres*, Arch. Math. **106**, 81-84, (2016).

Preprints:

1. H. Shah, *Geometry of asymptotically harmonic and Einstein manifolds with minimal horospheres*, submitted, (2017).

2. V. Schroeder and H. Shah, *Almost maximal volume entropy*, submitted, (2017), arXiv:1702.08859 [math.DG].

3. H. Shah, *Pinching theorem for critical exponent*, in preparation, (2017).

4. H. Shah, *Lichnerowicz conjecture for asymptotic harmonic manifolds*, in preparation, (2017).

Conference/Workshops Attended:

1. Conference in honour of 60th birthday of Prof. Ashoke Sen, Harish-Chandra Research Institute, Allahabad, India, August 2016.

Visits to other Institutes:

1. Universität Zürich, Switzerland, November - December 2016

2. University of Extremadura, Badajoz, Spain, September - November 2016

Invited Lectures/Seminars:

1. *Classification of 3-Dimensional Asymptotically Harmonic Manifolds*, Seminar at Universidad Extremadura, Spain, October 2016.

2. *Margulis Lemma*, conference in honour of 60th birthday of Prof. Ashoke Sen, Seminar at Harish-Chandra Research Institute, Allahabad, India, August 2016.

Academic recognition/Awards:

- Awarded visiting fellowship to viisit Universität Zürich, Switzerland, November - December 2016.
- Awarded visiting fellowship to viisit University of Extremadura, Badajoz, Spain, September - November 2016

Other Activities:

1. Guided Manoj Choudhuri, Post-doctoral student working in the area of Diophantine Approximation, Harish-Chandra Research Institute, Allahabad, India, September 2016 - March 2016.
   The paper: M. Choudhary, H. Shah, *Badly approximable vectors in Cantor like sets and Hausdorff dimension*, in preparation, 2017, evolved from the post-doctoral guidance of H. shah.
2. Member of Doctoral Committee of Rahul Kumar Singh, Graduate Student of Geometry, 2013 - present, Harish-Chandra Research Institute, Allahabad, India.
3. Graduate Students' Selection Committee, Harish-Chandra Research Institute, Allahabad, India, 2014 - present.

Ravindranathan Thangadurai

Research Summary:

During this academic year, we studied the divisibility of class numbers of quadratic fields and we are exploring a particular number divides the class numbers of quadratic number fields. In the transcendental number theory, we have been studying the four exponentials conjecture and its allied problems. More precisely, the Four exponentials conjecture states that for a given two pairs of $\mathbb{Q}$-linearly independent complex numbers (x_1, x_2) and (y_1, y_2), one of the following numbers, namely, $e^{x_1y_1}, e^{x_1y_2}, e^{x_2y_1}, e^{x_2y_2}$ is transcendental. We are exploring to prove this conjecture for some particular case and we have some evidence for some few cases. This is one of the hard problem in Transcendental Number Theory.

Publications:

1. M. N. Chintamani, P. Paul and R. Thangadurai, *On the EGZ constant on finite abelian groups*, To appear in:Integers, 2017.
2. N. K. Meher, K. Senthil Kumar and R. Thangadurai, On a theorem of Mahler, To appear in: Proc. Amer. Math. Soc. (Series A), 2017.

Preprints:

1. S. S. Rout and R. Thangadurai, *On l-th order gap balancing numbers*, (in preparation).
2. N. K. Meher and R. Thangadurai, *Decimal Expansion, Periodicity and Beyond*, (in preparation).
3. K. Senthil Kumar, Veekesh Kumar and R. Thangadurai, *Erdős Problem and Four Exponential Conjecture*, (in preparation).

Conference/Workshops Attended:

1. *Leauca 2016: M. Waldschmidt 70th birthday conference*, Italy, June, 2016.
2. *Symposium on Combinatorics at Indo-US conference*, India, December, 2016.
3. *Indian Mathematical Society Conference*, India, December, 2016.
4. *International Conference on Number Theory*, India, January, 2017.

Visits to other Institutes:

1. KIIT, Bhubaneshwar, June, 2016.
2. Government College of Arts and Science, Rasipuram, August, 2016.
3. University of Pune, Poona, October, 2016.

4. Central University of Tamil Nadu, December, 2016.
5. Beneras Hindu University, Varanasi, December, 2016.
6. Kalyani University, Kalyani, December, 2016.
7. Ramanujan Institue of Advanced Studies, Madras University, Chennai, January, 2017.
8. Government Engineering College, Thiruvananthapuram, January, 2017.
9. Kerala School of Mathematics, Kozhikode, January, 2017.

Invited Lectures/Seminars:

1. *Class group, Estimates on class numbers*, AIS on"Algebraic Number Theory", KIIT, Bhubaneswar, June, 2016.
2. *Elementary Number Theory*, Nurture: in the memory of S. S. Pillai, Govt. College, Rasipuram, August, 2016.
3. *Splitting of Primes, Chebotarev Density Theorem and its applications*, IST on "Algebraic Number Theory", Pune University, Pune, October, 2016.
4. *Computational Number Theory*, Nurture - 2016, Central University of Tamilnadu, Thiruvarur, December, 2016.
5. *On Mahler's Theorem*, Symposium on Combinatorics at Indo-US conference, BHU, Varanasi, December, 2016.
6. *Four Exponentials Conjecture and Erdos Problem*, Invited Talk in IMS conference, Kalyani University, Kalyani December, 2016.
7. *Decimal expansion and Mahler's Theorem*, S. S. Pillai Endowment talk, Ramanujan Institute of Advanced Studies, Madras University, Chennai, January, 2017.
8. *Computational Number Theory'*, 'Maths4CS" workshop for Kerala College Teachers Programme, Thiruvananthapuram, January, 2017.
9. *Mahler's Theorem - Borel's Conjecture*, International Conference on Number Theory, KSOM, Kozhikode, January, 2017.

Other Activities:

1. Organized 'Nurture - 2016' at Central University of Tamilnadu, Thiruvarur, December, 2016.
2. Organized 'Combinatorics and Number Theory Meet at HRI', February, 2017
3. Become 'Dean (Students' Affair) in January, 2017.
4. Convener of Transport Committee.
5. Member in Colloquium Committee and Faculty Advisory Committee.

Soumyarup Banerjee

Research Summary:

During last year, I am working on higher order Riesz sums to streamline Nakajimas result in 2-dimensional case and generalize it to the product of Hurwitz zeta- functions. A special and intriguing feature is that only the modified k-Bessel functions appear, which makes it possible to generalize the problem.

The signs of the Fourier coefficients of two cusp forms simultaneously for the principal congruence subgroup where the coefficients lie in an arithmetic progression are compared. The signs of Fourier coefficients of two cusp forms for sparse sequences are also compared. We are also trying to generalize this problem to Jacobi and Siegel modular forms.

Publications:

1. Nianliang Wang and Soumyarup Banerjee, *On the product of Hurwitz zeta-functions*, Proc. Jpn. Acad., Ser. A, **93**, 31-36, (2017).

Preprints:

1. Soumyarup banerjee, *A Note On Signs Of Fourier Coefficients Of two Cusp Forms* (in preparation).

2. Soumyarup Banerjee, Azizul Hoque and Kalyan Chakraborty *On the product of Dedekind zeta functions* (in preparation)

Conference/Workshops Attended:

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

2. *70-th Birthday conference of Prof. M. Waldschmidt.*, HRI, Allahabad, India, 6-7 September, 2016.

3. *School and workshop on modular forms and Blackholes*, NISER, Bhubaneswar, India, 5-14 January, 2017.

4. *Combinatorics and Number Theory meet*, HRI, Allahabad, India, 19-23 February, 2017.

Mithun Kumar Das

Research Summary:

In 1914, G. H. Hardy showed that the Rieman zeta function $\zeta(s) := \sum_{n=1}^{\infty} \frac{1}{n^s}$, $s = \sigma + it$, has infinitely many zeros on the critical line $\sigma = \frac{1}{2}$. For this purpose he defined a function $Z(t)$ called Hardy Z-function. Similarly many people have shown for other L-functions that these also have infinitely many zeros on the critical line. Recently, Gonek and Ivić studied the distribution of sign changes of $Z(t)$ quantitatively and proved that

$$\mu(\{T < t < 2T : Z(t) > 0\}) \gg T\ ;\ \mu(\{T < t < 2T : Z(t) < 0\}) \gg T$$

where μ is the Lebesgue measure. We did an extension of this result. Suppose χ is any Dirichlet character modulo a natural number q and the associated Dirichlet L-function $L(s, \chi) := \sum_{n=1}^{\infty} \frac{\chi(n)}{n^s}$, $s = \sigma + it$. We denote the corresponding Hardy Z-function by $Z(t, \chi)$. Then we show that a similar type of result, namely,

$$\mu(\{T < t < 2T : Z(t, \chi) > 0\}) \gg_q T\ ;\ \mu(\{T < t < 2T : Z(t, \chi) < 0\}) \gg_q T$$

holds. More generallay, $\chi_1, \chi_2, ..., \chi_r$ are arbitrary primitive Dirichlet characters modulo $q_1, q_2, ..., q_r$ respectively having same parity and $a_1, a_2, ..., a_r$ are arbitrary real numbers. Define the function $\Lambda(s)$ as follows:

$$\Lambda(s) := \sum_{j=1}^{r} a_j (\varrho(s, \chi))^{-\frac{1}{2}} L(s, \chi_j),$$

and along the critical line we define a real valued function as:

$$\Omega(t) := \Lambda\left(\frac{1}{2} + it\right) = \sum_{j=1}^{r} a_j Z(t, \chi_j).$$

Then we get the same result for $\Omega(t)$. I am also working on generalising this result for others L-functions.

Preprints:

1. Mithun Kumar Das, Sudhir Pujahari *Distribution of sign changes of Z-function* (in preparation)

Conference/Workshops Attended:

1. *Two days - Number Theory Meet at HRI*, India, September, 2016.
2. *International Conference on Number Theory at KSOM*, India, January, 2017.
3. *Combinatorics and Number Theory Meet @ HRI*, India, February, 2017.

Pradeep Das

Research Summary:

During this academic year I continued to work on the moduli of finite dimensional representations of a finite quiver with S. Manikandan and Prof. N. Raghavendra. We showed that the moduli of finite dimensional stable representations of a finite quiver carries a natural structure of a Kähler Manifold. We also showed that there is a natural positive line bundle on this moduli space whose Chern form is essentially a rational multiple of the Kähler form.

Preprints:

1. Pradeep Das, S. Manikandan and N. Raghavendra, *Holomorphic Aspects of Moduli of Representations of Quivers.* (submitted)

Other Activities:

1. Took a total of 16 hours of tutorials in *Annual Foundation School I*, Harish-Chandra Research Institute, December, 2016.

Sumana Hatui

Research Summary:

I had given my seminar talk in june 2016 with title *"A characterization of p-groups by their Schur multiplier"*. In this work we have classified non-abelian p-groups G of order p^n when $|M(G)| = p^{\frac{1}{2}n(n-1)-(n+1)}$.

Let $\gamma_2(G)$ denotes the commutator subgroup of group G. Rai classified p-groups G of order p^n having $|\gamma_2(G)| = p^k$ of nilpotency class 2 for which $|M(G)| = p^{\frac{1}{2}(n+k-2)(n-k-1)+1}$. In our article we proved that there is no finite p-group G of nilpotency class $c \geq 3$ for $p \neq 3$ such that $|M(G)|$ attains this bound. Hence $|M(G)| \leq p^{\frac{1}{2}(n+k-2)(n-k-1)}$ for p-groups G of class $c \geq 3$ where $p \neq 3$. We also construct a p-group G for $p = 3$ such that $|M(G)|$ attains this bound.

Recently we have studied the Schur multiplier of Central product of groups, which is joint work with L. R. Vermani and Manoj K. Yadav. Let G be a central product of its normal subgroups H and K with $A = H \cap K$, and $H^2(G, D)$ the second cohomology group of G with coefficients in D, where D is a divisible abelian group regarded as a trivial G-module. Let $Z := \gamma_2(H) \cap \gamma_2(K)$. First we proved that for any subgroup B of G such that $B \leq Z$, we have

$$H^2(G, D) \cong H^2(G/B, D)/N,$$

where $N \cong Hom(B, D)$. So this result reduce the study to the case when $Z = 1$.

Then we prove: $\big(H^2(H/A, D)/L \oplus H^2(K/A, D)/M\big)/N \oplus Hom(H/A \otimes K/A, D)$ embeds in $H^2(G, D)$ and $H^2(G, D)$ embeds in

$$\big(H^2(H/Z, D) \oplus H^2(K/Z, D)\big)/N \oplus Hom(H \otimes K, D),$$

where $L \cong Hom\big((A \cap H')/Z, D\big)$, $M \cong Hom\big((A \cap K')/Z, D\big)$ and $N \cong Hom(Z, D)$. In particular, when $D = \mathcal{C}^{\times}$, the multiplicative group of units of complex numbers, then we get the same results for Schur multiplier of G.

Publications:

1. Sumana Hatui, *A characterization of finite p-groups by their Schur multiplier,* Accepted for publication in Proc. Indian Acad. Sci. Sect. A Math. Sci (2017).

Preprints:

1. Sumana Hatui, *Finite p-groups having Schur multiplier of maximum order,* Submitted.

2. Sumana Hatui, L. R. Vermani, Manoj K. Yadav, *Schur multiplier of central product of groups,* Preprint.

Conference/Workshops Attended:

1. *Group Theory and Computational Methods*, ICTS Bangalore, India, 5th to 14th November, 2016.

Other Activities:

1. Tutor in Annual Foundation School-I on Complex Analysis, 5th to 31st December, 2016, HRI Allahabad, India.

2. Presented a poster ”A characterization of finite p-groups by their Schur multiplier” in conference Group Theory and Computational Methods, ICTS Bangalore, November 2016.

Arvind Kumar

Research Summary:

During the academic year 2016-2017, I was mainly involved in the problems concerning Hermitian Jacobi forms and nearly holomorphic modular forms.

The theory of Hermitian Jacobi forms along the lines of the classical Jacobi forms (developed by M. Eichler and D. Zagier) was first considered by K. Haverkamp in his thesis. However, in a recent work, O. Richter and J. Senadheera realized that the Hermitian Jacobi forms are classified into two different classes of forms, one with parity $+1$ and the other with parity -1. It is to be noted that these Hermitian Jacobi forms with parity ± 1 arise in a natural way (like in the case of classical Jacobi forms) via the Fourier-Jacobi coefficients of Hermitian modular forms of degree two with character $(\det)^l$, where l varies modulo 2. We have considered the Hermitian Jacobi forms of parity ± 1 in our setting.

1. Estimates for Fourier coefficients of Hermitian modular forms (joint work with Prof. B. Ramakrishnan).
We determine the Fourier series development of Hermitian Jacobi Poincaré series and obtain bounds for its Fourier coefficients. This gives rise to estimates for Fourier coefficients of Hermitian Jacobi cusp forms in general. Then, by following the method of W. Kohnen (*Estimates for Fourier coefficients of Siegel cusp forms of degree two*, Compositio Math. **87** (2) (1993)), we obtain estimates for Fourier coefficients of Hermitian cusp forms of degree two with respect to $\mathbf{Q}[i]$.

2. Converse theorem for Hermitian Jacobi forms (joint work with M. Pandey).
We prove a converse theorem for Hermitian Jacobi forms over $\mathbf{Q}[i]$. The case of classical Jacobi forms over $\mathbf{Q}$ is treated in two interesting papers by Y. Martin. Explicitly, we consider a function $\varphi(\tau, z, w)$ from $\mathbf{H} \times \mathbf{C}^2$ into $\mathbf{C}$ that have a Fourier expansion with certain condition on the Fourier coefficients. We show that φ is a Hermitian Jacobi form if and only if certain Dirichlet series associated with φ satisfy functional equation and some analytic properties.

3. The adjoint map of the Serre derivative and special values of shifted Dirichlet series.
We compute the adjoint of the Serre derivative map with respect to the Petersson scalar product by using existing tools of nearly holomorphic modular forms. The Fourier coefficients of a cusp form of integer weight k, constructed using this method, involve special values of certain shifted Dirichlet series associated with a given cusp form f of weight $k+2$. As application, we get an asymptotic bound for the special values of these shifted Dirichlet series and also relate these special values with the Fourier coefficients of f. We also give a formula for the Ramanujan tau function in terms of the special values of the shifted Dirichlet series associated to the Ramanujan delta function.

4. Rankin-Cohen brackets and identities among eigenforms (joint work with Dr. J. Meher).
We first define the Rankin-Cohen brackets for nearly holomorphic modular forms. We then investigate the cases for which the Rankin-Cohen brackets of two quasimodular eigenforms give rise to eigenforms. More precisely, we characterize all the cases in a subspace of the space of quasimodular forms for which Rankin-Cohen brackets of two quasimodular eigenforms are again eigenforms. Each of the cases corresponds to a similar case in the setting of nearly holomorphic modular forms. In the process, we

obtain some new polynomial identities among quasimodular eigenforms.

Publications:

1. A. Kumar and J. Meher, *On arbitrary products of eigenforms,* Acta Arithmatica **173 (3)**, 283–295, (2016).
2. A. Kumar, *Adjoint of Serre derivative map and special values of shifted Dirichlet series,* J. of Number Theory **177**, 516–527, (2017).

Preprints:

1. A. K. Jha and A. Kumar, *Construction of cusp forms using Rankin-Cohen bracket,* submitted.
2. A. Kumar and B. Ramakrishnan, Estimates for Fourier coefficients of Hermitian cusp forms of degree two, submitted.
3. A. Kumar and M. Pandey, *A converse theorem for Hermitian Jacobi forms*, preprint.
4. A. Kumar and J. Meher, *Rankin-Cohen brackets and identities among eigenforms,* in preparation.

Conference/Workshops Attended:

1. *31st Automorphic Forms Workshop*, East Tennessee State University, Johnson City, Tn, USA, 06-09 March, 2017.
2. *Combinatorics and Number Theory Meet*, On the occasion of 60-th birth anniversary of Prof. S. D. Adhikari, HRI, India, 19-23 Feb, 2017.
3. *School and Workshop on Modular Forms and Black Holes*, NISER, India, 05-14 Jan, 2017.
4. *Discussion Meeting on Automorphic forms*, NISER, India, 21-27 Dec, 2016.
5. *International conference of TIMC in corporation with AMS*, BHU, India, 14-17 Dec, 2016.
6. *Two days Number Theory Meet*, HRI, India, 06-07 Sept, 2016.
7. *Number Theory Conference on Arithmetic Geometry and L-Functions*, In honor of Prof. V Kumar Murty, KSOM, India, 17-21 Aug, 2016.
8. *Building Bridges: 3rd EU/US Summer School + Workshop on Automorphic Forms and Related Topics*, University of Sarajevo, Bosnia and Herzegovina, 11-22 July, 2016.
9. *Automorphic Forms on Metaplectic Groups and Related Topics*, IISER Pune, India, 04-09 July, 2016.

Visits to other Institutes:

1. Western Kentucky University, Bowling Green, Kentucky, USA, 10-14 March, 2017.
2. National Institute of Science Education and Research, Bhuabaneswar, India, 28 Dec, 2016-04 Jan, 2017.

Invited Lectures/Seminars:

1. *On the Serre derivative and its applications*, Western Kentucky University, Bowling Green, Kentucky, USA, 10-14 March, 2017.
2. *The adjoint map of the Serre derivative and its application*, 31st Automorphic Forms Workshop, East Tennessee State University, Johnson City, Tn, USA, 06-09 March, 2017.
3. *The adjoint map of the Serre derivative and its application*, Discussion Meeting on Automorphic forms, NISER, Bhubaneswar, India, 21-27 Dec, 2016.
4. *On arbitrary products of eigenforms*, Building Bridges: 3rd EU/US Workshop on Automorphic Forms and Related Topics, University of Sarajevo, Bosnia and Herzegovina, 18-22 July, 2016.
5. *On arbitrary products of eigenforms*, HRI, Allahabad, India, July, 2016.

Other Activities:

1. Tutor for the *Summer Programme in Mathematics* at HRI, Allahabad, 13 June-02 July, 2016.

Veekesh Kumar

Research Summary:

1. Let $b \geq 2$ be an integer and α be a non-zero real number written in b-ary expansion. In 2004, Adamczewski, Bugeaud and Luca provided a criterion for an irrational number to be a transcendental number using b-ary expansion. We had some remarks on this criterion and, under the assumption of Subspace Lang's conjecture, we extended this criterion for a much wider class of irrational numbers. In particular, we showed that the real number α satisfying the condition

$$\alpha = \sum_{n \geq 1} \frac{1}{10^{n[\log n]^2}}$$

is transcendental, which is a new transcendental result.

2. Many transcendental criterion for a real number written in b-ary expansion are known to us, using Subspace theorem. Currently, I am trying to generalize these critera for a real number written in Cantor Series expansion. Apart from these, we have been studying other papers in this related areas.

Publications:

1. Veekesh Kumar and Nabin Kumar Meher, *Subspace lang conjecture and some remarks on a transcendental criterion*, Proc. Math. Sci..

Conference/Workshops Attended:

1. *Leuca2016 Celebrating Michel Waldschmidt's 70th birthday*, Italy, June 2016.

2. *Two Days Number Theory Meet*, HRI, Allahabad, India, September 2016.

3. *Combinatorics and Number Theory Meet*, HRI, Allahabad, India, February 2017.

Academic recognition/Awards:

1. Harish-Chandra Memorial Award, 2016.

Kummari Mallesham

Research Summary:

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

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

In the third preprint listed below, we obtain an essentially optimal upper bound for the additive energy $E(A, B)$ of any subsets A and B of primes in the interval $[1, N]$ with relative density of A is $\alpha \in (0, 1)$ and B is non-empty.

In the fourth preprint listed below, we improve on a lower bound give for the density of subsets of primes to have a non trivial solution to a system of linear equations of "complexity one ", which improves on a bound of Kevin Henriot. Indeed, ours is a general result which yields a similar bound in the analogous problem for "Chen primes".

Let n be a positive integer and $P(n)$ denote the largest prime factor of n with the convention that $P(1) = 1$. Let x, y be two real numbers satisfying $x \geq y \geq 2$. A positive integer n is called y-smooth number if $P(n) \leq y$. Adolf Hildebrand and Gérald Tenenbaum, using the saddle-point method, gave an asymptotic formula for the number of y-smooth numbers upto x. We have been working on a related problem using the above method.

Preliminary versions of results contained in preprints 2 to 4 described above were obtained in the course of the preceding academic years. They are being put in final form at present.

Preprints:

1. Kummari Mallesham, *Primes in sumset* (submitted for publication)

2. Kummari Mallesham, Gyan Prakash, D.S Ramana, *On monochromatic representation of sums of squares of primes* (in preparation)

3. Kummari Mallesham, Gyan Prakash, D.S Ramana, *An Improved Bound for the Additive Energy of Dense Sets of Prime Numbers* (in preparation)

4. Kummari Mallesham, Gyan Prakash, *A generalization of Roth's theorem in primes* (in preparation)

Conference/Workshops Attended:

1. *Number Theory conference on Arithmetic Geometry and L-functions*, India, August, 2016.

2. *International Conference on Number Theory* , India, January, 2017.

3. *Combinatorics and Number Theory Meet*, India, February, 2017.

Invited Lectures/Seminars:

1. *Primes in Sumset*, Number Theory conference on Arithmetic Geometry and L-functions, KSOM, Kerala, January 2017.

Other Activities:

1. Tutor for the Algebra course in AFS-1, December, 2016.

S. Manikandan

Research Summary:

During this academic year I continued to work on the problem on the moduli of finite dimensional representations of a quiver with Pradeep Das and Prof. N. Raghavendra. We showed that the moduli space of finite dimensioanal stable representations of a quiver carries a natural structure of a kahler Manifold. We also showed that there is a natural positive line bundle on this moduli space whose chern form is a rational multiple of the kahler form.

Preprints:

1. Pradeep Das, S. Manikandan and N. Raghavendra, *Holomorphic Aspects of Moduli of representations of Quivers.* (submitted)

Invited Lectures/Seminars:

1. *Moduli of representations of finite-dimensional algebras*, Annual Semi- nar, HRI, Allahabad, July, 2016.

Other Activities:

1. Conducted 16 tutorial hours in the Annual Foundation School I, Harish-Chandra Research Institute, December, 2016.

Nabin Kumar Meher

Research Summary:

1. Let $b \geq 2$ be an integer and α be a non-zero real number written in base b. Let $B = b_0 b_1 \dots b_{k-1}$ be a given block of digits of length k in base b. For any real number $\alpha \in [0,1)$ and for any integer $m \geq 1$, we let

$$N_B(m,\alpha) := |\{i \ : \ a_i a_{i+1} \dots a_{i+k-1} = B, \text{ for any } i \leq m-k+1\}|$$

denote the number of times the given block B occurs in the first m digits of α in base b. The given block B of length k in base b is said to occur in the base b expansion of a real number α with the *frequency* ν, if

$$\lim_{m\to\infty} \frac{N_B(m,\alpha)}{m} = \nu.$$

A real number α is said to be *normal to base* b if for every integer $k \geq 1$, every block B of length k occurs in α with the frequency $1/b^k$. In 1909, E. Borel proved that with respect to Lebesgue measure, almost all real numbers are normal in all the bases $b \geq 2$ and conjectured that *Every algebraic irrational must be normal to base b for every integer* $b \geq 2$.

In 1973, Mahler proved the following result. *Let α be an irrational number written in base b. Then, there exists an integer X with $1 \leq X < b^{2k+1}$ such that B occurs infinitely often in the base b representation of the fractional part of* $\{X\alpha\}$.

In 1994, Berend and Boshernitzan proved the same result with $1 \leq X < 2b^{k+1}$. We obtained a result which is conditional quantitative version of Mahler's Theorem.

2. Let $b \geq 2$ be an integer and α is a non-zero real number written in b-ary expansion. In 2004, Adamczewski, Bugeaud and Luca provided a criterion for an irrational number to be a transcendental number using b-ary expansion. We had some remarks on this criterion and, under the assumption of Subspace Lang's conjecture, we extended this criterion for a much wider class of irrational numbers. In particular, we showed that the real number α satisfying the condition

$$\alpha = \sum_{n\geq 1} \frac{1}{10^{n[\log n]^2}}$$

is transcendental, which is a new transcendental result.

3. Other than these works, I have been looking at Mahler methods in Transcendental number theory and trying to apply these method in various contexts.

Publications:

1. N. K. Meher, K. Senthil Kumar and R. Thangadurai, *On a theorem of Mahler,* Proc. Amer. Math. Soc. , (To appear).

2. Nabin Kumar Meher and Veekesh Kumar, *Subspace lang conjecture and some remarks on a transcendental criterian,* Proc. Indian Acad. Sci. Math. Sci. (To appear).

Conference/Workshops Attended:

1. *Leuca2016 Celebrating Michel Waldschmidt's 70th birthday*, Italy, June, 2016.
2. *Two Days Number Theory Meet*, HRI, Allahabad, India, September, 2016.
3. *International Conference on Number Theory*, KSOM, Kerala, India, January, 2017.
4. *Combinatorics and Number Theory Meet at HRI*, HRI, Allahabad, India, February, 2017.

Tushar Kanta Naik

Research Summary:

In 1953, N. Ito proved that "to understand groups of conjugate rank 2, it is sufficient to study finite p-groups of conjugate type $\{1, p^n\}$ for $n \geq 1$". Half a century later, K. Ishikawa proved that finite p-groups of conjugate type $\{1, p^n\}$ can have nilpotency class at most 3. Then he classified p-groups of conjugate types $\{1, p\}$ and $\{1, p^2\}$ upto isoclinism. Last year, in a joint work with Manoj K. Yadav, we classified finite p-groups of conjugate type $\{1, p^3\}$ upto isoclinism and also proved that such groups can not be of nilpotency class 3.
So a natural question arises here that "for which $n \geq 4$, groups of conjugate type $\{1, p^n\}$ can have nilpotency class 3?". Working on this problem jointly with Rahul D. Kitture, we have constructed a group of conjugate type $\{1, p^4\}$ and nilpotency class 3. We are trying to answer some related questions such as:
(i) Is class 3 group of conjugate type $\{1, p^4\}$ unique upto isoclinism?
(ii) Does there exist any group of conjugate type $\{1, p^n\}$ and class 3, when n is odd?

Apart from this, I have been reading some research papers related to above mentioned work. Also, I have been reading the book "Character Theory of Finite Groups" by I.M.Isaacs.

Pre-Prints:

1. Tushar Kanta Naik and Rahul D. Kitture *On p-groups of conjugate rank 2 and nilpotency class 3.*

Conference Attended:

1. Group Theory and Computational Methods at ICTS, Bangalore, 05 - 14 November 2016.

Other Activities:

1. Presented a poster titled "*Classification of Finite p-groups of conjugate type $\{1, p^3\}$ upto isoclinism*" in the conference "Group Theory and Computational Methods at ICTS, Bangalore, 05 - 14 November 2016".

Manish Kumar Pandey

Research Summary:

Converse theorem for Hermitian Jacobi Forms (joint work with Arvind Kumar) : Converse theorem are old and important problem,it allows us to determine whether a certain form is a cusp form or not by looking at its associated L-function with certain properties of L-function. Having a converse theorem also enables us to define maps from space of one Automorphic form to other.We have considered this problem in the case of Hermitian Jacobi Forms. In coming days I am planning to work on a problem related to nonvanishing of twisted L-function of a half integral weight modular form. Also I plan to work on nonvanishing of Poincare series associated to Hermitian Jacobi Form.

Preprint:

1. Arvind Kumar,Manish Kumar Pandey *On the converse theorem for Hermitian Jacobi Forms*.

Conference/Workshops Attended:

1. *A Short Course on Modular Forms (August 24 - September 03, 2016)*, at Indian Institute of Science Education and Research (IISER), Bhopal.

2. *Conference on Modular Forms (4-th September 2016)* at Indian Institute of Science Education and Research (IISER), Bhopal.

3. *Discussion Meeting on Automorphic Forms (December 21 - 27, 2016)* at National Institute of Science Education and Research (NISER), Bhubaneswar.

4. *School and Workshop on Modular Forms and Black Holes (January 05 - 14, 2017)* at National Institute of Science Education and Research (NISER), Bhubaneswar.

5. *Combinatorics and Number Theory Meet (February 19 - 23, 2017)* at Harish-Chandra Research Institute (HRI), Allahabad.

Visits to other Institutes:

1. *Institute of Mathematical Sciences,Chennai,India,(10 May to 25 May 2017)*.

Bhuwanesh Rao Patil

Research Summary:

In the academic year 2016-17, I focussed on studying the additive and multiplicative structures in a subset of the set of integers. I have studied about a famous open question, first asked by Hindman, that if the set of natural numbers is finitely coloured, then do there exist x and y such that $x, y, x + y, xy$ all have the same colour? In 2016, a partial answer to this problem was given by Bergelson, Moreira, Green and Sanders. Bergelson and Moreira proved the existence of monochromatic triples of the type $(x, x + y, xy)$ in the set of integers using dynamical system. Ben Green and Tom Sanders answered an analogoue of this question in the affirmative when the set of natural numbers is replaced by a finite field of prime order. More precisely, they showed that if a finite field $\mathbb{Z}/p\mathbb{Z},$ where p is a prime number, is coloured with r colours, then there are at least $c(r)p^2$ monochromatic quadruples $\{x, y, x + y, xy\}$ where $c(r) > 0$ is a constant depending only upon r but is independent of the prime p. Presently, I am working on the problem of obtaining a generalisation of this result for a general finite field. More precisely, we are trying to show that if a finite field F_{p^n}, where p is a prime number, is coloured with r colours, then the number of monochromatic quadruples $\{x, y, x+y, xy\}$ is at least $c(r, n)p^2$, where $c(r, n) > 0$ is a constant depending only upon r and n but is independent of the prime $p.$

Besides this, I studied about another question asked by Beiglbock, Bergelson, Hindman and Strauss in the paper "Multiplicative structures in additively large sets". They asked the question of existence of a 3-term geometric progression with integer common ratio in an additive syndetic set A. One can get infinitely many 2-term geometric progressions with integer common ratio in an additive syndetic set. But the existence of a 2-term geometric progession with integer square common ratio in an additive syndetic set is not known.

Conference/Workshops Attended:

1. *International Conference on Number Theory*, KSOM 9th-13th January 2017
2. *TIMC-BHU International Conference*,BHU Varanasi, 14th- 17th Dec 2016
3. *Combinatorics and Number Theory Meet*, HRI, Allahabad, 19th-22nd February, 2017

Pramod Eyyunni

Research Summary

I am currently working on a problem in the area of expanders, a subfield of additive combinatorics. This area has its origins in a conjecture given by Erdös and Szemeredi called the sum-product phenomenon which says that a finite subset of integers cannot have both additive as well as multiplicative structure. This has been generalised in multiple directions to various fields and to other expressions of finite subsets involving sums and products of their elements, i.e. expanders. There is a rich interplay between this area and incidence geometry. The problem I am working on, to prove that AB(A+B) is an expander where A and B are subsets of a finite field, is equivalent to proving an upper bound for the number of incidences between sets of points and quadratic curves over finite fields. There have been some results in this direction for special curves like circles, spheres and generalized spheres. I am trying to adapt the spectral graph theoretical and elementary techniques used in the case of the above bounds to the current problem of point-quadratic curve bounds.

Conference/Workshops Attended:

1. *TIMC-BHU International Conference BHU*, Varanasi, December, 2016.
2. *International Conference on Number Theory* , Kerala School of Mathematics, Kozhikode, January, 2017.
3. *Combinatorics and Number Theory Meet*,HRI, Allahabad, February, 2017.

Ritika Sharma

Research Summary:

I have read the method of Levin-Feinleib which helps us to find summatory function of non-negative multiplicative function. In joint work with Amandine Saldana we generalized the method of Levin-Feinleib for multiplicative function which is oscillating and takes more positive values than negative values.

Preprints:

1. Ritika Sharma and Amandine Saldana, *On Average order of oscillating multiplicative function*, preprint.

Conference/Workshops Attended:

1. *Number Theory meet at HRI*, INDIA, September, 2016.

2. *Combinotorics and Number Theory meet at HRI*, INDIA, February, 2017.

Anup Kumar Singh

Research Summary:

1. Representation numbers for certain classes of quadratic forms in eight variables (joint work with Balakrishnan Ramakrishnan and Brundaban Sahu): Finding formulas for the number of representations of a positive integer as sum of squares is an important problem. Instead of taking sum of squares, we can think of same problem for any other kind of quadratic forms. Given any quadratic form, the corresponding theta series associated to this quadratic form, corresponds to a modular form of certain weight and level (weight depends on the number of variables of the form where as the level depends on the nature of the quadratic form). There are many number theoretic techniques to deal with such problem. We use the theory of modular forms for the following works.

(i) In first work, we find formulas for the number of representations of some diagonal octonary quadratic forms with coefficients $1, 2, 3, 4$ and 6. We obtain these formulas by constructing explicit bases of the space of modular forms of weight 4 on $\Gamma_0(48)$ with character. This work has been submitted for publication.

(ii) In this work, we find formulas for the number of representations of certain class of quadratic forms in eight variables, viz., forms of the form $a_1x_1^2 + a_2x_2^2 + a_3x_3^2 + a_4x_4^2 + b_1(x_5^2 + x_5x_6 + x_6^2) + b_2(x_7^2 + x_7x_8 + x_8^2)$, where a_i's $\in \{1, 2, 3\}$, b_i's $\in \{1, 2, 4\}$ and $a_1 \leq a_2 \leq a_3 \leq a_4$, $b_1 \leq b_2$. We also determine formulas for the number of representations of a positive integer by the quadratic forms $(x_1^2 + x_1x_2 + x_2^2) + c_1(x_3^2 + x_3x_4 + x_4^2) + c_2(x_5^2 + x_5x_6 + x_6^2) + c_3(x_7^2 + x_7x_8 + x_8^2)$, where $c_1, c_2, c_3 \in \{1, 2, 4, 8\}$ and $c_1 \leq c_2 \leq c_3$. This work has been submitted for publication.

(iii) In third work, we consider the quadratic form $Q : x_1^2+x_1x_2+2x_2^2+x_1^2+x_1x_2+2x_2^2$ and find formulas for the number of representations of the quadratic forms $Q \oplus jQ$, where $j \in \{1, 2, 3, 4\}$. By expressing these formulas in terms of certain convolution sums, we deduce evaluation of the convolution sums $W_{j,7}(n)$ for $j = 1, 2, 3, 4$. This work has been submitted for publication.

2. A new formula for the Ramanujan Tau function (joint work with Balakrishnan Ramakrishnan and Brundaban Sahu): In this work, we find the number of representations of the quadratic form $x_1^2 + x_1x_2 + x_2^2 + \ldots + x_{2k-1}^2 + x_{2k-1}x_{2k} + x_{2k}^2$, for $k = 7, 9, 11, 12, 14$ using the theory of modular forms. By comparing our formulas with the formulas obtained by G. A. Lomadze, we obtain the Fourier coefficients of certain newforms of level 3 and weights $7, 9, 11$ in terms of certain finite sums involving the solutions of similar quadratic forms of lower variables. In the case of 24 variables, comparison of these formulas gives rise to a new formula for the Ramanujan Tau function. This work has been submitted for publication.

Preprints:

1. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of a positive integer by certain classes of quadratic forms in eight variables*, Accepted for publication.

2. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations by certain octonary quadratic forms with coefficients* $1, 2, 3, 4$ *and* 6, Submitted for publication.

3. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of certain quadratic forms in* 8 *variables,* Submitted for publication.

4. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of certain quadratic forms and a formula for the Ramanujan Tau function,* Submitted for publication.

Conference/Workshops Attended:

1. *Number Theory conference on Arithmetic Geometry and L - Function (August 17-21, 2016)* at Kerala School of Mathematics (KSOM), Kozhikode.

2. *A Short Course on Modular Forms (August 24 - September 03, 2016)*, at Indian Institute of Science Education and Research (IISER), Bhopal.

3. *Conference on Modular Forms (4-th September 2016)* at Indian Institute of Science Education and Research (IISER), Bhopal.

4. *Discussion Meeting on Automorphic Forms (December 21 - 27, 2016)* at National Institute of Science Education and Research (NISER), Bhubaneswar.

5. *School and Workshop on Modular Forms and Black Holes (January 05 - 14, 2017)* at National Institute of Science Education and Research (NISER), Bhubaneswar.

6. *Combinatorics and Number Theory Meet (February 19 - 23, 2017)* at Harish-Chandra Research Institute (HRI), Allahabad.

Visits to other Institutes:

1. *National Institute of Science Education and Research (NISER), Bhubaneswar, India (28th December 2016 to 4th January 2017).*

Anoop Singh

Research Summary:

In the academic year 2016-2017, I read the work of Rudakov on stability structures in an abelian category. Also, I read about purity and satbility of coherent sheaves on a variety. I gave 12 lectures on these topics in a seminar at HRI.

I am working on extending a criterion of Atiyah and Weil for the existence of holomorphic connections over compact Riemann surfaces to curves over more general field, and to families of curves.

Conference/Workshops Attended:

1. *Advanced Instructional School On Algebraic Geometry*, India, May, 2016.
2. *Workshop On Local Cohomology*, India, June, 2016.
3. *Workshop On Geometry and Analysis on CR-Manifolds*, India, October, 2016.

Academic recognition/Awards:

- Harish-Chandra Memorial Award, 2016

Other Activities:

1. Conducted 16 hours of tutorials in Topology in Annual Foundation School-I, December, 2016

Rahul Kumar Singh

Research Summary:

A maximal surface in a three dimensional Lorentz-Minkowski space is a spacelike surface such that the mean curvature vainshes at every point. In general, a maximal surface can have singularities (i.e., those points where the metric degenerates), then we call it a generalised maximal surface. In 2007 Kim and Yang, introduced and proved the singular Björling problem. We have revisited this problem for the case of a closed analytic curve and have given a different proof of the same. As an application, we have shown (see below) the existence of a maximal surface which contains a given curve and has a special singularity.

Any smooth function $\varphi(x,t)$ which is a solution to the Born-Infeld equation

$$(1+\varphi_x^2)\varphi_{tt} - 2\varphi_x\varphi_t\varphi_{xt} + (\varphi_t^2 - 1)\varphi_{xx} = 0. \tag{1}$$

is known as Born-Infeld soliton.
A graph $(x,t,f(x,t))$ in Lorentz-Minkowski space is maximal if it satisfies

$$(1-f_x^2)f_{tt} + 2f_xf_tf_{xt} + (1-f_t^2)f_{xx} = 0, \tag{2}$$

for some smooth function $f(x,t)$ satisfying $f_x^2 + f_t^2 < 1$. This equation is known as maximal surface equation.

It is interesting to note that the Born-Infeld equation is related to the maximal surface equation by a wick rotation in the variable x i.e., replacing the variable x by ix. It is known that the Born-Infeld equation is related to the minimal surface equation in Euclidean space via a wick rotation in the variable t. We have explored the interrelation between Born-Infeld equation and maximal surface equation and have obtained some interesting results.

Publications:

1. R. Dey and R.K. Singh, *Born-Infeld solitons, maximal surfaces, Ramanujan's identities,* Arch. Math.(Basel) **108-5**, 527–538, (2017)

Preprints:

1. R. Dey, P. Kumar, R.K. Singh, *Existence of maximal surface containing given curve and special singularity,* arxiv.org/abs/1612.06757

2. R.K. Singh, *Weierstrass-Enneper representation for maximal surfaces in hodographic coordinates,* arxiv.org/abs/1607.07562

Conference/Workshops Attended:

1. *Young Researcher Workshop on Differential Geometry in Minkowski Space*, Spain, April, 2017.

2. *International Conference on Number Theory held at Kerala School of Mathematics*, India, January, 2017.

3. *International Conference of The Indian Mathematics Consortium (TIMC) in cooperation with AMS held at BHU*, India, December, 2016.

4. *Geometry and Analysis on CR manifolds held at Harish-Chandra Research Institute*, India, October, 2016.

Visits to other Institutes:

1. ICTS, Bangalore, India, June, 2016,

2. ICTS, Bangalore, India, April 2017.

Invited Lectures/Seminars:

1. *Maximal surfaces, Born-Infeld solitons, and Ramanujan's identities*, Young Researcher Workshop on Differential Geometry in Minkowski Space, University of Granada, Granada, April, 2017.

Gopal Datt

Research Summary:

I have joined Harish-Chandra Research Institute, Allahabad on February 28, 2017. During the period February 28, 2017 – March 31, 2017, I started to work on a problem which is summarized as follows. My research interest is in the area of complex analysis of one and several variables. More specifically, I am interested in the normal families of meromorphic mappings which take values on non-hyperbolic complex manifolds. We are working on the following problem:

- Problem:- Let $\alpha \not\equiv 0$ and $\beta \neq 0$ be two holomorphic functions in D. Let $n > 2$ be a positive integer, and $\mathcal{F}$ be a family of meromorphic functions, having zeros of multiplicity at least 2, on D. Suppose that for each pair f, g in $\mathcal{F}$, $f + \beta(f^{'})^n$ and $g + \beta(g^{'})^n$ share α in D. Then, show that $\mathcal{F}$ is normal in D.

Saibal Ganguli

Research Summary:

After joining HRI I have been collaborating with Professor Rukmini Dey. We have worked on Geometric quantization and have calculated the dimension of the Hilbert space of quantization of Vortex Moduli. We have also quantized Toda systems , described the Hilbert space of quantization, found unitary representations and described coherent states. This has resulted in two articles, one accepted and other in referee process. In the following we give a brief description of the above mentioned work.

Geometric Quantization: Given a symplectic manifold (M, ω), with ω integral (i.e. its cohomology class is in $H^2(M, \mathbb{Z})$), geometric pre-quantization is the construction of a Hermitian line bundle (called the pre-quantum line bundle) with a connection whose curvature ρ is proportional to the symplectic form. This is always possible as long as ω is integral. This method of quantization developed by Kostant and Souriau, assigns to functions $f \in C^\infty(M)$, an operator, $\hat{f} = -i\nabla_{X_f} + f$ acting on the Hilbert space of square integrable sections of L (the wave functions). Here $\nabla = d - i\theta$ where locally $\omega = d\theta$ and X_f is defined by $\omega(X_f, \cdot) = -df(\cdot)$.This assignment has the property that that the Poisson bracket (induced by the symplectic form), namely, $\{f_1, f_2\}_{PB}$ corresponds to an operator proportional to the commutator $[\hat{f}_1, \hat{f}_2]$ for any two functions f_1, f_2. The Hilbert space of pre-quantization is usually too huge for most purposes. Geometric quantization involves construction of a polarization of the symplectic manifold such that we now take polarized sections of the line bundle, yielding a finite dimensional Hilbert space in most cases. However, $\hat{f}$ does not map the polarized Hilbert space to the polarized Hilbert space in general. Thus only a few observables from the set of all $f \in C^\infty(M)$ are quantizable. When M is a compact Kähler manifold, ω is an integral Kähler form, and L the prequantum line bundle, there is a special kind of polarization called holomorphic polarization where polarized sections are in one-one correspondence with holomorphic sections of the bundle.

Finding dimension of Holomorphic Quantization of vortex moduli: A vortex is a pair (A, ϕ) where A is a unitary connection of a principal $U(1)$ bundle over a Riemann surface Σ and ϕ a section of the associated line bundle $\mathcal{L}$, solving an extremal equation. There is an action of the gauge group on these solutions and the quotient space is the vortex moduli. The moduli space is equivalent to $Symm^N(\Sigma)$(symmetric product) where N is the Chern class of $\mathcal{L}$. It is quantized by the Manton-Nasir form which is a Kahler form on the moduli space and the quantum bundle is called L. We calculated the dimension of the holomorphic sections of the bundle L to be $\binom{\frac{A}{4\pi}}{N}$, where A is the area of the Riemann surface. For details see [5]

Quntization of Toda Systems: The connection between finite Toda system and coadjoint orbits was first explored by Adler [1]. Adler goes on to show that the system has a coadjoint orbit description of the group of lower triangular matrices with non-zero diagonal and it is shown to be homeomorphic to $\mathbb{R}_+{}^{n-1} \times \mathbb{R}^{n-1}$. We describe this precisely and show that the Toda system corresponds to a single orbit. We explore it further to geometrically quantize the Toda system. This is possible since the orbit has a symplectic structure . In two famous papers [2],[3] Kostant describes the Kostant-Souriau quantization in general and for coadjoint orbits in particular. Using his construction, we were able to construct an infinite dimensional Hilbert-space of polarized sections of the quantum bundle (which is trivial in our case). The polarized sections are square integrable functions of a_i, $i = 1, ..., (n-1)$(the ${\mathbb{R}_+}^{n-1}$ part of the space). In this construction we modified the usual volume (given by the symplectic form) by an exponential decay. The group of lower triangular matrices with determinant 1 and positive diagonal entries acts on this Hilbert space giving in fact a unitary representation.Next, we construct Rawnsley coherent states, [4], of the Toda system corresponding to this quantization. There is another definition of coherent states for orbits. The coherent states are obtained by moving any "vacuum" vector by the group action. We show for orbit quantization, these two notions of coherent states coincide. We also find the expression for the quantum Hamiltonian. For details see [6].

Present work: Moduli spaces arising from physics like BPS-Monopole moduli have nice geometrical structures like Kahler and Hyperkahler structures due to the underlying symmetries of the actions from which they arise. Professor Dey and I are exploring when these spaces are algebraic and whether there is any connection between algebraic structures and the symmetries of the action. This project is in progress and I hope our investigations will produce successful results.

Bibliography

1. Adler M., On a Trace Functional for Formal Pseudo-Differential Operators and the Symplectic Structure of the Korteweg-Devries Type Equations, lnventiones Math. **50** (1979) 219-248.

2. Kostant B.,*Quantization and Unitary Representations*, Lecture Notes in Math., vol **170** Springer, Berlin 1970 87-208.

3. Kostant B., Orbits and Quantization Theory, Actes Congres Intern.Math. Nice., Vol.**2** (1970) 395-400.

4. Rawnsley J.H., Coherent states and Kahler maifolds Quart. J. Math. Oxford Ser. (2) 28 (1977), no. 112, 403415 .

5. Dey R. and Ganguli S. The Hilbert space of quantization of vortices on a Riemann surface arxiv 1606.03810.

6. Dey R. and Ganguli S. Geometric quantization of finite Toda systems and coherent States arXiv:1612.02987

Publications:

1. Saibal Ganguli, *On Hodge Structures opf quasitoric orbifold* J. Korean Math. Soc. 2017 **Vol. 54, No. 3, 733-748..**

2. Rukmini Dey,Saibal Ganguli *The Hilbert space of quantization of vortices on a Riemann surface,* To appear International Journal of Geometric methods in Modern Physics

Preprints:

1. Dey R. and Ganguli S. *Geometric quantization of finite Toda systems and coherent States* arXiv:1612.02987 (submitted)

Azizul Haque

Research Summary:

The ideal class group or more precisely the class numbers of numbers fields is one of the fundamental and mysterious objects in number theory. Y. Kishi and K. Miyake gave a parameterization of quadratic fields with class number divisible by a given integer $g > 1$. This permitted to enlarge the list of families of quadratic fields with this property. To this list we have contributed some simply parameterized families of real as well as imaginary quadratic fields each with class number divisible by a given integer $g > 1$. We have constructed a nice family of imaginary quadratic fields each with class number divisible by a given integer $g > 1$. It is also proved that such a family has infinitely many members.

D. Byeon and E. Lee proved that there are infinitely many imaginary quadratic fields whose ideal class group has an element of order $2g$, g being a positive integer, and whose discriminant has only two prime factors. In this context, we have proved a similar result, but the discriminant has exactly n-prime factors. In fact, this result is also true for real quadratic fields. We have also provided a lower bound on the number of such fields.

We have obtained some results on the solvability of certain Pell-type equations, and these results are then used to discussed the class numbers of maximal real subfields of certain cyclotomic fields. We have corrected a theorem of I. Yamaguchi [I. Yamaguchi, On the class numbers of the maximal real subfield of a cyclotomic field, J. Reine Angew. Math., 272 (1975)] as the theorem was not accurate and has many applications. By using this theorem, we have discussed the divisibility of the class numbers of certain maximal real subfields.

Publications:

1. H. Kalita, A. Hoque and H. K. Saikia *On ξ-torsion modules,* Boll. Unione Mat. Ital., **10 (2)**, 223-228, (2017).

Preprints:

1. Kalyan Chakraborty, Azizul Hoque, Yasuhiro Kishi, Prem Prakash Pandey, *Divisibility of the class numbers of imaginary quadratic fields,* (submitted for publication).

2. Azizul Hoque, Kalyan Chakraborty, *Divisibility of class numbers of certain families of quadratic fields,* (submitted for publication).

3. Azizul Hoque, Kalyan Chakraborty, *Pell-type equations and class number of the maximal real subfield of a cyclotomic field,* (submitted for publication).

4. Soumyarup Banerjee, Azizul Hoque, Kalyan Chakraborty, *On the product of two Dedekind zeta functions,* arXiv:1611.08693v1 [math.NT].

5. Azizul Hoque, Helen K. Saikia, *A note on the divisibility of class number and discriminant of quadratic fields,* (submitted for publication).

6. Azizul Hoque, Kalyan Chakraborty, *On a theorem of Yamaguchi and class number of the maximal real subfield of a cyclotomic field*, (in preparation).

Conference/Workshops Attended:

1. *The 13-th International conference in Number Theory and Smarandache problems*, China, March, 2017.

2. *Combinatorics and Number Theory Meet*, India, February, 2017.

3. *The 82nd Annual Conference of the Indian Mathematical Society*, India, December, 2016.

4. *National Conference on Advances in Mathematical Sciences*, India, December, 2016.

5. *Two day– Number Theory Meet*, India, September, 2016.

Visits to other Institutes:

1. Northwest University, Xi'an, China, March, 2017.

2. Hong Kong University, Hong Kong, March, 2017.

3. Gauhati University, Guwahati, India, 2016.

Invited Lectures/Seminars:

1. *Divisibility of the class numbers of certain quadratic fields*, Colloquium, Hong Kong Univerity, Hong Kong, March, 2017.

2. *Class number properties of some real quadratic fields*, The 13-th International conference in Number Theory and Smarandache problems, Shangluo University, China, March, 2017.

3. *On the divisibility of the class numbers of certain real quadratic fields*, The 82nd Annual Conference of the Indian Mathematical Society, Kalyani Univerity, Kolkata, December, 2016.

4. *Continued fractions and Gauss conjecture on class numbers* , National Conference on Advances in Mathematical Sciences, Gauhati Univerity, Guwahati, December, 2016.

5. *On the Class Numbers of Certain Number Fields*, Two day– Number Theory Meet, HRI, Allahabad, September, 2016.

Rahul Dattatraya Kitture

Research Summary:

Introduction: A group G is said to be of conjugate type $(1, m_2, \cdots, m_r)$ if $1 < m_2 < \cdots < m_r$ and these integers are precisely all the sizes of conjugacy classes of G. In other words, these are precisely the *distinct* integers which appear in the class equation of G.

This notion was introduced by N. Ito in 1953. His first three papers on this topic, titled *Finite groups of given conjugate type - I, II, III* (1953, 1970, 1970) study the structure of finite groups with the above defined invariant. In these papers, Ito didn't mentions any motivation for studying groups w.r.t. the above invariant, but later, he started (1972, 1973) to study *finite simple groups* and classify them according to such an invariant (the classification of finite simple groups at that time was incomplete).

Later, the study of structure of finite groups w.r.t a conjugate-type was done by various mathematicians along independent directions. An interesting result get proved by Kenta Ishikawa (2000), saying that

A group of conjugate type $(1, m)$ is nilpotent of class at most 3.

This was a striking result since before it, no one had guessed about such restriction on nilpotency class of groups (of conjugate type $(1, m)$). It was further generalized by Martin Isaacs and Avinoam Mann. This raises a question:

Can we classify groups of conjugate type $(1, p^k)$ with p a prime and $k \geq 1$?

The classification is known for conjugate type $(1, p)$, $(1, p^2)$ (by Ishikawa, 2000) and $(1, p^3)$ (by Tushar Naik and Manoj Yadav, 2016-17). However, the proofs in these classification use almost different tools, and it is difficult to generalize their arguments to classify groups of conjugate type $(1, p^k)$ for arbitrary k.

Work done: I started a joint work with Manoj Yadav and Tushar Naik, by observing some patterns in the known classification. Namely for $p > 2$,

1. Groups of conjugate type $(1, p)$ with nilpotency class 3 *do not exist*.
2. Groups of conjugate type $(1, p^2)$ with class 3 *exists* (Ishikawa, 2000).
3. Groups of conjugate type $(1, p^3)$ with class 3 *do not exist* (Naik, Yadav, 2016).

It was not known whether the groups of conjugate type $(1, p^4)$ and class 3 exists. If such a group exists, we determined certain necessary conditions on it, summarized below:

Suppose there is a group G of conjugate type $(1, p^4)$ and class 3. With no loss of generality, we can put some restrictions on G such as - G is of exponent p ($p > 2$) and $Z(G) \leq G'$. Then the following should hold:

(a) G is generated by *at least* 4 elements (in particular $|G/G'| \geq p^4$).

(b) $|Z(G)| \geq p^4$.

(c) If $|G/G'| = p^4$ then $|G'/Z(G)| \geq p^2$.

Later, we observed, by all possible enumerations of groups with above three properties in GAP, that *there exists* a group of conjugate type $(1, p^4)$ and class 3, and it is a group attaining the bounds in (1), (b), (c). Thus,

4. Groups of conjugate type $(1, p^4)$ with class 3 *exists* (Naik,Yadav, me).

Now the statements (1)-(4) suggest the following general possible pattern: for an integer $m \geq 1$,

(i) Group of conjugate type $(1, p^{2m-1})$ with class 3 *do not exist*.

(ii) Group of conjugate type $(1, p^{2m})$ with class 3 *exist*.

Manoj Yadav recently visited Italy and from his discussion with Carlo Scoppola, we came to know that the groups with property in (ii) have been constructed (in a different context) by R. Dark and C. Scoppola in 1996. Our guess is that such groups are *unique* up to certain equivalence relation. This is because, it is known (Ishikawa, 2000) that the groups of conjugate type $(1, p^2)$ and class 3 are unique (up to an equivalence relation). On the other hand, it seems, from further discussion of groups of conjugate type $(1, p^4)$, class 3, that they should *attain* all the bounds in (a), (b), (c), and so they should be of order p^{10}. We have shown that *among groups of order* p^{10}, the groups of conjugate type $(1, p^4)$ and class 3 are unique (up to isomorphism). We are also trying to prove the non-existence in (i) by defining a skew-symmetric bilinear form on G/G'.

Publications:

- R. D. Kitture, M. K. Yadav, *Note on Caranti's method of construction of Miller groups* Monatshefte fur Mathematik **(to appear) (2017)** DOI: 10.1007/s00605-016-0976-z.

Preprints:

1. R. D. Kitture, M. K. Yadav *Non-abelian groups with abelian automorphism groups: a survey* preprint

Conference/Workshops Attended:

1. *Group Theory and Computational Methods*, Ramanujan Lecture Hall, ICTS Bangalore, 05-14 Nov. 2016.

Invited Lectures/Seminars:

1. *Lectures on Group Theory (one week) and Tutorials in Algebra (three weeks)*, Summer Program in Mathematics, HRI, Allahabad, June 2016.

Rani Kumari

Research Summary:

The paper discusses a series of results concerning reproducing kernel Hilbert spaces, related to the factorization of their kernels. In particular, it is proved that for a large class of spaces isometric multipliers are trivial. One also gives for certain spaces conditions for obtaining a particular type of dilation, as well as a classification of Brehmer type submodules.

Publications:

1. Kumari, Rani; Sarkar, Jaydeb; Sarkar, Srijan; Timotin, Dan, *Factorizations of kernels and reproducing kernel Hilbert spaces*, Integral Equations Operator Theory, **87(2)**, 225– 244, (2017).

Ramesh Manna

Research Summary:

During the last one year, I have been studying the local smoothing estimates for the Fourier integral operator of the form

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

where the amplitude function $a(x,t,\xi) \in S^m(\mathbb{R}^n \times \mathbb{R} \times \mathbb{R}^n)$, the symbol class of order $m \leq 0$. In the context of wave equation, Sogge (1991) showed that there is an $\epsilon(p) > 0$ such that the inequality

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

holds for $2 < p < \infty$.

We obtain the local smoothing estimate of order $\epsilon(p) = \frac{1}{2p}$, $p \geq 4$ for the Fourier integral operator of the form [1] in dimensions two. Proof of the refined estimate of this type involves frequency localization with suitable smooth cut off functions which form a partition of unity, a duality argument and delicate machinery from Littlewood-Paley theory and the wave front statement.

Preprints:

1. Ramesh Manna, P. K. Ratnakumar, *On Local Smoothing of Fourier Integral Operators in two Dimensions*, (submitted).

Conference/Workshops Attended:

1. October 10-17, 2016, **Workshop on Geometry and Analysis on CR Manifolds**, HRI Allahabad, India.

Other Activities:

1. Compiled HRI Annual Report for the academic year 2015-2016, May-July 2016.

Raj Kumar Mistri

Research Summary:

Throughout the academic year 2016-2017, I have been working on some problems in Additive Number Theory. A brief description of the research work is presented below. Let $A \subseteq \mathbb{Z}$ and $B \subseteq \mathbb{Z}$ be nonempty finite sets and let r be a nonzero integer. The sum of dilates of A and B is defined as $A + r \cdot B := \{a + rb : a \in A \text{ and } b \in B\}$. Finding nontrivial lower bound for the sum of dilates is an important problem in additive combinatorics. In case of $A = B$, a recent result of Freiman et al. states that if $r \geq 3$, then $|A + r \cdot A| \geq 4|A| - 4$. We generalized this result for the sum of dilates $A + r \cdot B$ for two nonempty finite sets A and B of integers, where r is an integer with $|r| \geq 3$. We proved that $|A + r \cdot B| \geq 4|A| - 4$, where the sets A and B satisfy certain conditions.

I have been working on some other related problems also. The work is in progress.

Publications:

1. Raj Kumar Mistri, *Sum of dilates of two sets,* Notes Number Theory Discrete Math. (Accepted).

Conference/Workshops Attended:

1. *Combinatorics and Number Theory Meet at HRI, India*, February, 2017.

2. *Triveni Number Theory Meet @ HRI, Allahabad*, India, March, 2016.

Other Activities:

1. Delivered a talk on *Cardinality and Structural Classification Problems for Some Special Sumsets*, Department of Mathematics, HRI, Allahabad, India, February, 2017.

2. Delivered a talk on *Generalized Sumset: Direct and Inverse Problems*, Two Days Number Theory Meet (06 - 07 September 2016) at Department of Mathematics, HRI, Allahabad, India, September, 2016.

3. Delivered a talk on *Sum of Dilates of Multiple Sets*, Department of Mathematics, HRI, Allahabad, India, July, 2016.

Saudamini Nayak

Research Summary:

During the accademic perion May 2016-March 2017 period I have been working in two projects. In one project our aim is to classify nilpotent Lie superalgebras through Schurs multiplier. In this direction we prove that all finite dimensional special Heisenberg Lie superalgebras with even center have same dimension, say $(2m+1 \mid n)$ for some non-negative integers m, n and are isomorphism with them. Further, for a nilpotent Lie superalgebra L of dimension $(m \mid n)$ and $\dim(L') = (r \mid s)$ with $r + s \geq 1$, we find the upper bound $\dim \mathcal{M}(L) \leq \frac{1}{2}[(m+n+r+s-2)(m+n-r-s-1)] + n + 1$, where $\mathcal{M}(L)$ denotes the Schur multiplier of L.
Moreover, if $(r, s) = (1, 0)$ (respectively $(r, s) = (0, 1)$), then the equality holds if and only if $L \cong H(1, 0) \oplus A_1$ (respectively $H(0, 1) \oplus A_2$), where A_1 and A_2 are abelian Lie superalgebras with $\dim A_1 = (m-3 \mid n), \dim A_2 = (m-1 \mid n-1)$ and $H(1, 0), H(0, 1)$ are special Heisenberg Lie superalgebras of dimension 3 and 2 respectively.

In the second project we try to compute supersymmetric spaces and semi symmetricsuper spaces of $A(3|1), A(1|1)$ and $A(2|2)$ in detail. Every real simple Lie superalgebra is either a realified complex classical Lie superalgebra or the real forms of a complex classical Lie superalgebra. Further there is a one-to-one correpondance between the real forms of a complex classical Lie superalgebra g and the set of involutive antilinaer automorphisms on g which is given by $\phi \mapsto g^\phi = \{x + \phi(x) | x \in g\}$. We know for complex simple Lie algebra h the relation between real Lie algebras of h and involutive automorphisms on h is one-one and also every complex simple Lie superalgebra has a unique compact real form. So starting from the compact real form of a compex simple Lie algebra, then having a Cartan decomposition, rest non-compact real forms can be obtained following Weyl unitary trick. But for the Lie superalgebras case situation is little different as all complex classical Lie superalgebras does not possess a compact real form. Our aim is to show that like the case of Lie algebras, Weyl unitary trick does work for those complex classical Lie superalgebras, having compact real forms and hence to obtain all the real forms of g starting from the compact real form and following Weyl unitary trick. Further we want to classify all super symmetric spaces which are, homogeneous supermanifolds G/G^ϕ where G is a real Lie superalgebra and ϕ is involutive automorphism of G. This can be viewed as analogous of symmetric spaces given by the pair (t, θ), where t is a real Lie lagebra and θ is an involution on t.

Publications:

1. Saudamini Nayak, *Schur multiplier of nilpotent Lie superalgebras*, communicated.

Preprints:

1. Saudamini Nayak, *Characterisation of nilpotent Lie superalgebras*, Inpreparation.

2. Saudamini Nayak, Punita Batra, K.C. Pati *Super-symmetric spaces and semisymmetric-super spaces associated with* $A(3|1), A(1|1)$ *and* $A(2|2)$, in preparation.

Shubhankar Podder

Research Summary:

I have joined Harish-Chandra Research Institute, Allahabad on March 08, 2017 as a Post-Doctoral Fellow. During the period March 08, 2017-March 31, 2017, I have started to work on some problems which are summarized as follows.

My research interest is in the area of operator theory. More specifically, I am interested in the reflexivity of operators. In 1980, Olin and Thomson proved that every subnormal operator is reflexive. So, naturally one can ask the following question in multivariable invariant subspace theory.

- Is a subnormal tuple reflexive?

The above question has not been settled yet in complete generality, though positive results are available for some special subnormal tuples. I am currently working on the following problems.

- Finding new classes of operator tuples which are reflexive.
- Is the dual of a subnormal tuple reflexive?

Sudhir Kumar Pujahari

Research Summary:

In the academic year 2016-2017, I have done the following research work:

1. Distinguishing Hecke eigenforms:

   Given two L-functions, it is of great interest to number theorists to know whether they both are same or not? To investigate the above question there are very few techniques available in the literature. In the course of research of the above question, I have written the following article jointly with M. Ram Murty. In the paper, which is a part of my thesis we have given a criterion in terms of the upper density of coefficients at prime indices such that a Hecke eigenform will be a character twist of another. In particular, we have prove the following:

   Given two normalized Hecke eigenforms f_1 and f_2 of weights k_1, k_2 and levels N_1, N_2 respectively, let

   $$f_i(z) = \sum_{n=1}^{\infty} a_n(f_i) n^{(k_i-1)/2} q^n, \qquad q = e^{2\pi i z}, \qquad i = 1, 2,$$

   be the Fourier expansions at infinity. We have proved the following:

   Theorem: Suppose that at least one of f_1, f_2 is not of CM type. If

   $$\limsup_{x\to\infty} \frac{\#\{p \le x : a_p(f_1) = a_p(f_2)\}}{x/\log x} > 0,$$

   then $f_1 = f_2 \otimes \chi$ for some Dirichlet character χ. In particular, by modularity theorem we have,

   Corollary: if E_1 and E_2 are two elliptic curves defined over the field of rationals, with at least one of them not of CM type, such that

   $$card(E_1(F_p)) = card(E_2(F_p)),$$

   for a set of primes of positive lower density, then E_1 and E_2 become isogenous after base change.

   We also have reported the joint Sato-Tate conjecture for two Hecke eigenforms.

2. Effective Joint distribution of eigenvalues of Hecke operators:

   Let $\{x_n\}_{n=1}^{\infty}$ and $\{y_m\}_{m=1}^{\infty}$ be two equidistributed sequences with respect to probability measures μ_1 and μ_2 in an interval $[a, b]$. It is of great interest to study how the family

   $$\{(x_n, y_m)\}_{n,m=1}^{\infty} \subset [0, 1]^2$$

   will be distributed. Moreover, if we know the rate of convergence of $\{x_n\}_{n=1}^{\infty}$ and $\{y_m\}_{m=1}^{\infty}$ to their distribution measure then what will be the corresponding rate of convergence of the family $\{(x_n, y_m)\}_{n,m=1}^{\infty}$ to it's distribution measure? In this direction, we proved the following theorem;

Let $p_1, p_2, ..., p_r$ be r fixed primes. Let

$$\{a_{i_j}(p_i), 1 \leq i \leq r, 1 \leq j \leq s(N,k)\}$$

be the set of eigenvalues of the normalized Hecke operators $T^{'}_{p_i}$ acting on the space of cusp forms, where $s(N,k)$ is the dimension of the space of cusp forms of weight k and level N (say $S(N,K)$).

Theorem: Let $p_1, p_2, ...p_r$ be distinct primes. Let k be positive even integer such that $r\log(p_1p_2\dots p_r) \leq \delta \log k$, for some small absolutely constant δ. Let $a_i(p_i)$ be the eigenvalues of normalized Hecke operators $T^{'}_{p_i}$ acting on $S(N,k)$.

For some $I = [\alpha_n, \beta_n]^r \subset [-2,2]^r$,

$$\frac{1}{s(N,k)} \sharp \{1 \leq i_j \leq r, j = 1,2,...,r : (a_{i_1}(p_1),...,a_{i_r}(p_r)) \in I\}$$

$$= \int_I \prod_{n=1}^{r} d\mu_{p_n} + \emptyset\left(\frac{r\log(p_1p_2\dots p_r)}{\log(kN)}\right),$$

where $d\mu_{p_n} = \frac{p_n+1}{\pi}\frac{\sqrt{1-\frac{x^2}{4}}}{(p_n^{\frac{1}{2}}+p_n^{-\frac{1}{2}})^2-x^2}dx.$

Publications:

1. Ram Murty and Sudhir Pujahari, *Distinguishing Hecke eigenforms,* Proc. Amer. Math. Soc., 145 (2017), 1899-1904.

Preprints:

1. S. Pujahari, Effective joint equidistribution of eigenvalues of Hecke operators, (preprint), (Arxiv link: arXiv:1703.07944).

Conference/Workshops Attended:

1. 2017 (19th February-23th February) Harish-Chandra Research Institute, Combinatorics and Number Theory meet.

2. 31st Automorphic Forms Workshop, East Tennessee State University, U.S.A, (6th March-9th March) 2017.

3. 2016 - 2017 (05th January - 14th January) National Institute of Science Education and Research, School and workshop on modular forms and Blackholes.

4. Discussion meeting on Automorphic forms, NISER, (21th December - 27th December) 2016 .

5. 2016 (14th December - 17th December) Banaras Hindu University, International Conference of The Indian Mathematics Consortium (TIMC) in cooperation with American Mathematical Society (AMS).

6. 70-th Birthday conference of prof. M. Waldschmidt, Harichchandra Research Institute, Allahabad, (7th September) 2016 .
7. Conference on Modular Forms, IISER Bhopal, 4th September, 2016.
8. Advanced Instructional School on Analytic theory of algebraic numbers, KIIT Bhubaneswar, (13th June - 2nd July), 2016.
9. 2016 (24th August - 03 September) IISER Bhopal, A short course on Modular Forms.

Visits to other Institutes:

1. The University of Illinois at Urbana-Champaign, Champaign, U.S.A, March, 2017.

Invited Lectures/Seminars:

1. In the neighbourhood of Sato-Tate conjecture, Number Theory Seminar, The University of Illinois at Urbana-Champaign, (14th March), 2017.
2. Effective joint distribution of eigenvalues of Hecke operators, Spring 2017, UIUC: MATH 532 Analytic Theory of Numbers II, The University of Illinois at Urbana-Champaign, U.S.A, (14th March) 2017.
3. 31st Automorphic Forms Workshop, Distinguishing Hecke eigenforms, East Tennessee State University, U.S.A, (6th March-9th March) 2017.
4. Arithmatic statistics of Automorphic forms, Discussion meeting on Automorphic forms, NISER, (21th December - 27th December) 2016 .
5. Statistics of eigenvalues of Hecke operators, 70-th Birthday conference of prof. M. Waldschmidt, Harichchandra Research Institute, Allahabad, (7th September) 2016 .
6. Arithmetic statistics of modular forms, Conference on Modular Forms, IISER Bhopal, 4th September, 2016.
7. Basic Algebraic number theory, Teaching assistant, Advanced Instructional School on Analytic theory of algebraic numbers, KIIT Bhubaneswar, (13th June - 2nd July), 2016.

Rameez Raja

Research Summary:

I joined HRI as a post-doctoral fellow on 03-03-2016. During the academic year 2016-2017, I worked on Combinatorial aspects arising from algebraic structures (Modules and Rings). The description of the research work which I did at HRI is the following. Let M be an R- module, where R is a commutative ring with unity and let Γ be a simple graph. Any subset of M is called as an object. A combinatorial object is an object which can be put into one-to-one correspondence with a finite set of integers and an algebraic object is a combinatorial object which is also an algebraic structure. The main objective of my research was to study combinatorial objects, objects arising from modules and the graphs with vertex set as objects and combinatorial objects. This research area of an interplay between combinatorial and algebraic properties of M is the beginning to study the correspondence between the essential ideals in R, submodules of M and the vertices of graphs arising from M. Moreover, the theory of perfect codes is an area in coding theory which has a base in graph theory as well. I introduced these codes to the graphs arising from commutative rings (zero-divisor graphs).

Preprints:

1. Rameez Raja, *On combinatorial aspects arising from modules over commutative rings*, (submitted).

2. Rameez Raja, *Perfect codes in zero-divisor graphs*, (in preparation).

Conference/Workshops Attended:

Combinatorics and Number Theory Meet, Feb 19 - 23, 2017, HRI, Alld.

Visits to other Institutes:

School of Mathematics, TIFR, Mumbai during 16 August to 27 September, 2016.

Academic recognition/Awards:

Got a recognition as a reviewer for Mathematical Reviews/MathSciNet.

Biswajit Ransingh

Research Summary:

The study of cluster algebras was initiated by Fomin and Zelevinsky in 2001. Cluster algebras are commutative rings with a set of distinguished generators called cluster variables. These algebras are different from usual algebras in the sense that they are not presented at the outset by a complete set of generators and relations. Instead, an initial seed consisting of initial cluster variables and an exchange matrix is given and then using an iterative process called mutation, rest of the cluster variables are generated. The initial motivation behind study of these algebras was to provide an algebraic and combinatorial framework for Lusztig's work on canonical bases but now the study of cluster algebras has gone far beyond that initial motivation. Cluster algebras now have connections to string theory, Poisson geometry, algebraic geometry, combinatorics, representation theory and Teichmuller theory. Cluster algebras provide a unifying algebraic and combinatorial framework for wide variety of phenomenon in above mentioned settings. We propose a notion of cluster superalgebras which is synronization with classical cluster algebra.

Preprints:

1. Li Li, Biswajit Ransingh and Ashish K. Srivastav, *An introduction to cluster superalgebras*, preprint

Conference/Workshops Attended:

1. *Representation theory*, Germany, August, 2016.

Visits to other Institutes:

1. University of Cologne, Germany, August, 2016.
2. IIT Kanpur, Kanpur, India, October, 2016.

Sudhansu Sekhar Rout

Research Summary:

My broad area of research is number theory. In particular, I am interested in the study of integer sequences that arise in elementary number theory and in a combinatorial setting. Most of my work revolves around binary number sequences, and more specifically balancing number sequences. Also, I have done some work related to Diophantine equations which arises from number sequence problems. Here I am describing the summary of my research work for the academic year 2016-17.

Let $\{u_n\}_{n\geq 0}$ be a non-degenerate binary recurrence sequence with positive discriminant and p be a fixed prime number. In this paper, we have shown a finiteness result for the solutions of the Diophantine equation $u_{n_1} + u_{n_2} + \cdots + u_{n_t} = p^z$ with $n_1 \geq n_2 \geq \cdots \geq n_t \geq 0$. Moreover, we explicitly find all the powers of three which are sums of three balancing numbers using the lower bounds for linear forms in logarithms. Further, we use a variant of Baker-Davenport reduction method in Diophantine approximation due to Dujella and Pethő. This is a joint work with E. Mazumdar.

With N. Meher, we extend the above result and we obtain the finiteness result for the solution of the Diophantine equation $U_{n_1} + \cdots + U_{n_t} = b_1 p_1^{z_1} + \cdots + b_s p_s^{z_s}$ under certain assumptions. Moreover, we explicitly solve the equation $F_{n_1} + F_{n_2} = 2^{z_1} + 3^{z_2}$, in non-negative integers n_1, n_2, z_1, z_2 with $z_2 \geq z_1$.

In another paper, we consider the Diophantine equation $u_m + u_n = a_1 n_1! + \cdots + a_k n_k!$ and prove that there are only finitely many effectively computable terms u_m and u_n such that their sum can be expressed as linear cominations of factorials.

In a joint paper with P. Das, P.K. Dey and B. Maji, we consider the problem about finding out perfect powers in alternating sum of consecutive cubes. More precisely, we completely solve the Diophantine equation $(x+1)^3 - (x+2)^3 + \cdots - (x+2d)^3 + (x+2d+1)^3 = z^p$, where p is prime and x, d, z are integers with $1 \leq d \leq 50$. In another paper, we completely solve the Diophantine equation $(x-2)^5 - (x-1)^5 + x^5 - (x+1)^5 + (x+2)^5 = z^n$, where x, z and n are integers with $n \geq 2$.

Publications:

1. P.K. Dey and S. S. Rout, *Diophantine equations concerning balancing and Lucas balancing numbers*, Arch. Math. (Basel) **108**(1) (2017), 29–43.

Preprints:

1. P. Das, P.K. Dey and S. S. Rout, *Perfect powers in alternating sum of consecutive powers*, submitted for publication.

2. P. Das, P.K. Dey, B. Maji and S. S. Rout, *Perfect powers in alternating sum of consecutive cubes*, arXiv:1705.02597v2.

3. N. Meher and S. S. Rout, *Linear combinations of prime powers in sums of terms of binary recurrence sequences*, arXiv:1612.05869.

4. S. S. Rout, *Linear combinations of factorials in binary recurrence sequences*, arXiv:1611.05618.

5. E. Mazumdar and S. S. Rout, *Prime powers in sums of terms of binary recurrence sequences*, arXiv: 1610:02774.

Conference/Workshops Attended:

1. School and Workshop on Modular forms and Black holes (Jan 05-14, 2017) NISER Bhubaneswar, India.

2. International Conference of The Indian Mathematical Consortium in cooperation with American Mathematical Society (Dec 14-17, 2016) Banaras Hindu University, Varanasi, India.

3. Number Theory Meet (Sep 06-07, 2016) HRI, Allahabad, India.

Visits to other Institutes:

1. University of Debrecen, Hungary (May 08- June 02, 2017).

2. Indian Statistical Institute Delhi, India (Dec 19 - 30, 2016).

3. National Institute of Technology Rourkela, India (July 25 - August 04, 2016).

Invited Lectures/Seminars:

1. Gave a talk at University of Debrecen, Hungary in May, 2017 on 'Lucas-Wieferich primes and abc-conjecture'

2. Gave a talk in the Number Theory Meet at Harish-Chandra Research Institute Allahabad, in Sep. 2016 on 'Balancing non-Wieferich primes in arithmetic progression'.

Shailesh Trivedi

During the period 1-04-2016 to 31-03-2017, I have worked on the theory of *weighted shifts and multishifts on directed graphs*. This is a joint work with Prof. Sameer Chavan, Indian Institute of Technology, Kanpur, and Deepak Kumar Pradhan, Indian Institute of Technology, Kanpur. The research work is summarized below.

Research Summary:

We systematically develop the multivariable counterpart of the theory of weighted shifts on rooted directed trees. Capitalizing on the theory of product of directed graphs, we introduce and study the notion of multishifts on directed Cartesian product of rooted directed trees. This framework unifies the theory of weighted shifts on rooted directed trees and that of classical unilateral multishifts. Moreover, this setup brings into picture some new phenomena such as the appearance of system of linear equations in the eigenvalue problem for the adjoint of a multishift. First, we focus our attention mostly on the multivariable spectral theory and function theory including finer analysis of various joint spectra and wandering subspace property for multishifts. Later, we separate out two special classes of multishifts, which we refer to as torally balanced and spherically balanced multishifts. The classification of these two classes is closely related to toral and spherical polar decompositions of multishifts. Furthermore, we exhibit a family of spherically balanced multishifts on d-fold directed Cartesian product T of rooted directed trees. These multishifts turn out be multiplication d-tuples $\mathsf{M}_{\mathsf{z,a}}$ on certain reproducing kernel Hilbert spaces H_{a} of vector-valued holomorphic functions defined on the unit ball $\mathbb{B}^d$ in $\mathbb{C}^d$, which can be thought of as tree analogs of the multiplication d-tuples acting on the reproducing kernel Hilbert spaces associated with the kernels $\frac{1}{(1-\langle z,w\rangle)^a}$ $(z, w \in \mathbb{B}^d, a \in \mathbb{N})$. Indeed, the reproducing kernels associated with H_{a} are certain operator linear combinations of $\frac{1}{(1-\langle z,w\rangle)^a}$ and multivariable hypergeometric functions ${}_2F_1(\alpha_v + a + 1, 1, \alpha_v + 2, \cdot)$ defined on $\mathbb{B}^d \times \mathbb{B}^d$, where α_v denotes the depth of a branching vertex v in T. We also classify joint subnormal and joint hyponormal multishifts within the class of spherically balanced multishifts.

Let T be a leafless, locally finite rooted directed tree. We associate with T a one parameter family of Dirichlet spaces H_{q} ($\mathsf{q} \geq 1$), which turn out to be Hilbert spaces of vector-valued holomorphic functions defined on the unit disc $\mathbb{D}$ in the complex plane. These spaces can be realized as reproducing kernel Hilbert spaces associated with the positive definite kernel

$$\begin{aligned}\kappa_{\mathsf{H}_{\mathsf{q}}}(z,w) &= \sum_{n=0}^{\infty} \frac{(1)_n}{(q)_n} z^n \overline{w}^n P_{\langle e_{\mathsf{root}} \rangle} \\ &+ \sum_{v \in V_{\prec}} \sum_{n=0}^{\infty} \frac{(n_v + 2)_n}{(n_v + q + 1)_n} z^n \overline{w}^n P_v \ (z, w \in \mathbb{D}),\end{aligned}$$

where $V_{\prec}$ denotes the set of branching vertices of T, n_v denotes the depth of $v \in V$ in T, and $P_{\langle e_{\mathsf{root}} \rangle}$, P_v $(v \in V_{\prec})$ are certain orthogonal projections. Further, we discuss the question of unitary equivalence of operators $\mathsf{M}_{\mathsf{z}}^{(1)}$ and $\mathsf{M}_{\mathsf{z}}^{(2)}$ of multiplication by z on Dirichlet spaces H_{q} associated with directed trees T_1 and T_2 respectively.

Publications:

1. S. Chavan, D. Pradhan and S. Trivedi, *Multishifts on Directed Cartesian Product of Rooted Directed Trees,* Dissertationes Mathematicae, *to appear.*

Preprints:

1. S. Chavan, D. Pradhan and S. Trivedi, *Multishifts on Directed Cartesian Product of Rooted Directed Trees,* arXiv:1607.03860.

2. S. Chavan, D. Pradhan and S. Trivedi, *Dirichlet Spaces Associated with Locally Finite Rooted Directed Trees,* arXiv:1702.02308.

Conference/Workshops Attended:

1. *International Workshop and Conference on "Recent Advances in Operator Theory and Operator Algebras 2016"*, India (ISI, Bangalore), December 2016.

Visits to other Institutes:

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

2. Indian Institute of Technology Kanpur, Kanpur, India, October 2016.

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

Invited Lectures/Seminars:

1. *Complex Analysis*, Annual Foundation School-I, Harish-Chandra Research Institute, Allahabad, December, 2016.

Abhitosh Upadhyay

Research Summary:

During academic session 2016-17, we study biconservative hypersurfaces in space form, particularly in S^n and H^n . We obtain complete explicit classification of biconservative hypersurfaces in 4-dimensional Riemannian space form with exactly three distinct principal curvatures. More recently, we study biconservative submanifolds in $S^n \times R$ and $H^n \times R$ with parallel mean curvature vector field. We obtained necessary and sufficient conditions for a such submanifold to be biconservative. In particular, we obtain a new family of 3-dimensional biconservative submanifolds in $S^4 \times R$ and $H^n \times R$. We also get some results for biharmonic submanifolds in $S^4 \times R$ and $H^n \times R$.

Further, we study f-biharmonic and bi-f-harmonic submanifolds in both generalized complex and Sasakian space forms. First, we prove necessary and sufficient condition for f-biharmonicity and bi-f-harmonicity in the general case and then obtained many particular cases. Some non-existence results are also obtained

Furthermore, we study stable cmc free-boundary surfaces in a strictly convex domain of a bi-invariant Lie group. We prove that if $\Sigma \subset \Omega$ is a stable CMC free-boundary surface in Ω then Σ has genus either 0 or 1, and at most 3 boundary components. This result was proved by I. Nunes and A. Ros for the case where $G = R^3$, slightly improving a result proved by Ros-Vergasta, and proved by R. Souam for the case where $G = S^3$ and Ω is a geodesic ball with radius $r < \frac{\pi}{2}$, excluding the possibility of Σ having 3 boundary components. Besides R^3 and S^3, our result also apply to the spaces $S^1 \times S^1 \times S^1$, $S^1 \times R^2$, $S^1 \times S^1 \times R$ and $SO(3)$. When $G = S^3$ and Ω is a geodesic ball with radius $r < \frac{\pi}{2}$, we obtain that is Σ is stable than Σ is a totally umbilical disc. In order to prove those results, we use an extended stability inequality and a modified Hersch type balancing argument to get a better control on the genus and on the number of connected components of the boundary of the surfaces.

Publications:

1. Julien Roth and Abhitosh Upadhyay, *Biharmonic submanifolds of Generalized Space Forms,* Differential Geometry and its Applications **50**, 88–104, (2017).

2. Abhitosh Upadhyay and Nurettin Cenk Turgay, *A Classification of Biconservative Hypersurfaces in a Pseudo-Euclidean Space,* J. Math. Anal. Appl. **444**, 1703–1720, (2016).

Preprints:

1. Julien Roth and Abhitosh Upadhyay, *f-biharmonic and bi-f-harmonic submanifolds of generalized space forms,* arXiv:1609.08599, (2016).

2. Nurettin Cenk Turgay and Abhitosh Upadhyay, *On biconservative hypersurfaces in 4-dimensional Riemannian space forms,* arXiv:1702.05469, (2016).

3. Fernando Manfio, Nurettin Cenk Turgay and Abhitosh Upadhyay, *Biconservative submanifolds in $S^n \times R$ and $H^n \times R$,* arXiv:1703.08517, (2017).

4. Abhitosh Upadhyay, Fernando Etayo and Rafael Santamara, *On the geometry of almost Golden Riemannian manifolds*, arXiv:1704.00926, (2017).

5. Ezequiel Barbosa, Farley Santana and Abhitosh Upadhyay, *On stable cmc free-boundary surfaces in a strictly convex domain of a bi-invariant Lie group*, (Submitted).

6. Abhitosh Upadhyay and Julien Roth, *Isometric immersions into manifolds with metallic structures*, (in preparation).

Conference/Workshops Attended:

1. *Workshop on Geometry and Analysis on CR Manifolds*, in Harish Chandra Research Institute, Allahabad, India, 10-17 October, 2016.

Invited Lectures/Seminars:

1. *Some classification results on biconservative hypersurfaces of Product spaces*, The International conference of the Indian Mathematcs Consortium in cooperation with American Mathematical Society, Banaras Hindu University, India, 14-17 December, 2016.

2. *A classification of biconservative hyeprsurfaces in a pseudo-Euclidean space*, seminar talk, Harish-Chandra Research Institute, India, 06 December, 2016.

3. *Recent results on biconservative submanifolds in semi-Euclidean spaces*, the International workshop on theory of submanifolds, Istanbul Technical University, Turkey, 02-04 June, 2016.

Academic recognition/Awards:

- Travel grant from Science and Engineering Research Board (SERB), India to attend Harmonic Maps workshop-2017 to be held in Brest, France during 15-18 May, 2017.

Ramdin Mawia

Research Summary:

My tenure at the Harish-Chandra Research Institute as a post-doctoral fellow was extended for one year on the 24^{th} August, 2016. From then on, I have been working on the following themes. Continuing my work on Hardy's function and other topics, I have written the following articles.

Publications

1. On the distribution of values of Hardy's Z-function in short intervals(***accepted***).

Preprints

1. On the distribution of values of Hardy's Z-function in short intervals II. The q-aspect (in preparation).

2. A note on standard zero-free regions for Rankin-Selberg L-functions (in preparation, with Satadal Ganguly (ISI Kolkata)).

3. A visual strategy for the game of SIM (in prep., with S. Ram (IIITD)).

4. On the distribution of smooth numbers. (in preparation, with Mithun Das and Kummari Mallesham).

Conferences and schools attended

1. *CIMPA-ICTP School on Artin L-functions, Artin's primitive roots conjecture and applications*, 29 May-9 June 2017, Nesin Mathematics Village, irince, Turkey.

2. *Combinatorics and Number Theory Meet, a conference in honour of the 60th birthday of Prof. SD Adhikari*, February 19-23, 2017, HRI, Allahabad, India.

3. *Number Theory Meet, a conference in honour of the 70th birthday of J-M Deshouillers*, January 9-13, 2017, KSOM, Kerala, India.

4. *Two-Days Number Theory Meet, in honour of M. Waldschmidt*, September 6-7, 2016, Allahabad, India.

Visit to other institutes

- ISI Kolkata, April 3-28, 2017.

Academic Report - Physics

Anirban Basu

Research Summary:

The effective action of string theory encodes information about scattering matrices. We have analyzed the low momentum expansion of the four and five graviton amplitudes in string theory at one loop. They involve evaluating integrals over the fundamental domain of $SL(2, Z)$, where the integrands are given by modular graph functions. We have proven relations satisfied by them which enable us to calculate these amplitudes. These relations result from Poisson equations satisfied by them leading to non–trivial relations between graphs with distinct topologies. The proofs involve using Green function techniques to obtain the Poisson equations as the links of the graphs are given by Green functions or their derivatives on the toroidal worldsheet.

We have also obtained non–analytic terms for BPS interactions from the structure of nested ultraviolet divergences in maximal supergravity upto three loops. These logarithmically divergent contributions have been evaluated using dimensional regularization, with the coefficients establishing several results in the literature. We also obtain a new contribution for the $1/8$ BPS interaction in four dimensions.

Publications:

1. Anirban Basu, *Non–analytic terms from nested divergences in maximal supergravity,* Class.Quant.Grav. **33 no.14**, 145007, (2016).

2. Anirban Basu, *Poisson equation for the three loop ladder diagram in string theory at genus one,* Int.J.Mod.Phys. A **31 no.32**, 1650169, (2016).

3. Anirban Basu, *Proving relations between modular graph functions,* Class.Quant.Grav. **33 no.23**, 235011, (2016).

Preprints:

1. Anirban Basu, *Simplifying the one loop five graviton amplitude in type IIB string theory,* arXiv:1608.02056.

Conference/Workshops Attended:

1. *Automorphic forms, mock modular forms and string theory*, Simons Center for Geometry and Physics, Stonybrook, New York, USA, September, 2016.

2. *String Theory: the Present and the Future*, Belur Vidyamandir, Belur, Kolkata, India, September, 2016.

3. *International Strings Meeting 2016*, IISER Pune, India, December, 2016.

Invited Lectures/Seminars:

1. *Proving relations between modular graph functions*, HRI, Allahabad, July, 2016.

2. *Some relations between modular graph functions*, Simons Center for Geometry and Physics, Stonybrook, New York, September, 2016.

3. *Corrections to General Relativity from String Theory*, Belur Vidyamandir, Belur, Kolkata, September, 2016.

4. *Some relations between modular graph functions*, IISER, Pune, December, 2016.

5. *Low Momentum Expansion of One Loop String Amplitudes*, Quantum Spacetime Seminar, TIFR, Mumbai, January, 2017.

6. *Low Momentum Expansion of One Loop String Amplitudes*, STSS Seminar, SINP, Kolkata, February, 2016.

7. *String loop amplitudes and U-duality*, Five lectures, IMSc, Chennai, March, 2017.

Other Activities:

1. Taught course on Conformal Field Theory at HRI, Aug-Dec, 2016.

Sandhya Choubey

Research Summary:

Explaining of the origin of nonzero neutrino masses and dark matter (DM) are two of the principal challenges which theoretical high energy physics has been facing over the last few decades. Neutrinos were predicted to be massless in the Standard Model (SM) of particle physics. However, a series to top-notch experimental results have firmly established the existence of neutrino massed and mixing. The presence of dark matter in the Universe is also now well established. Its presence has been probed by its gravitational interaction with the visible world such as the rotation curve of spiral galaxies, gravitational lensing, and the phenomena of the Bullet cluster. Meanwhile, the amount of dark matter present in the Universe has already been measured with an unprecedented accuracy by various satellite borne experiments like WMAP and Planck. We have worked on models beyond the standard model which allow for simultaneous explanation of neutrino masses and dark matter observations.

In (JHEP 1608 (2016) 114) we considered a gauged $U(1)_{\mathrm{B-L}}$ extension of the Standard Model (SM) with three right handed neutrinos for anomaly cancellation and two additional SM singlet complex scalars with nontrivial B-L charges. One of these is used to spontaneously break the $U(1)_{\mathrm{B-L}}$ gauge symmetry, leading to Majorana masses for the neutrinos through the standard Type I seesaw mechanism, while the other becomes the dark matter (DM) candidate in the model. We tested the viability of the model to simultaneously explain the DM relic density observed in the CMB data as well as the Galactic Centre (GC) γ-ray excess seen by Fermi-LAT. We showed that for DM masses in the range 40-55 GeV and for a wide range of $U(1)_{\mathrm{B-L}}$ gauge boson masses, one can satisfy both these constraints if the additional neutral Higgs scalar has a mass around the resonance region. In studying the dark matter phenomenology and GC excess, we took into account theoretical as well as experimental constraints coming from vacuum stability condition, Planck bound on DM relic density, LHC and LUX and presented allowed areas in the model parameter space consistent with all relevant data, calculated the predicted gamma ray flux from the GC and discussed the related phenomenology.

In (arXiv:1704.00819) we worked with a slightly different variant of the $U(1)_{\mathrm{B-L}}$ extension of the Standard Model (SM). Here we considered TeV scale RH Majorana neutrinos, which can be interesting phenomenologically. We chose two of the RH neutrino masses to be nearly degenerate, which allowed us to generate a lepton asymmetry via resonant leptogenesis. This lepton asymmetry is converted to the baryon asymmetry through sphaleron processes allowing us to correctly reproduce the observed matter-antimatter asymmetry of the Universe. Finally, the second new scalar which is charged neither under the SM gauge group nor the $\mathrm{U}(1)_{\mathrm{B-L}}$ gauge group was made stable by adding a Z_2 symmetry. We showed that this particle can easily play the role of the dark matter of the Universe. Since so far there has been no conclusive evidence of a particle dark matter in any experiment, this puts a tight constraint on the coupling of the dark matter with the SM. Therefore, we considered our dark matter candidate to be very feebly interacting with the cosmic soup and hence it is called the FIMP or Feebly Interacting Massive Particle, which never attains thermal equilibrium. We studied in detail the production of the dark matter before and after electroweak symmetry breaking and used the observed dark matter relic abundance to put constraints on the model parameters.

In another model (JHEP 1609 (2016) 147) we proposed to extend the SM by a local $L_\mu - L_\tau$ gauge symmetry, two additional complex scalars and three right-handed neutrinos. The $L_\mu - L_\tau$ gauge symmetry is broken spontaneously when one of the scalars acquires a vacuum expectation value. The $L_\mu - L_\tau$ gauge symmetry is known to be anomaly free and can explain the beyond SM measurement of the anomalous muon $(g-2)$ through additional contribution arising from the extra $Z_{\mu\tau}$ mediated diagram. Small neutrino masses were explained naturally through the Type-I seesaw mechanism, while the mixing angles were predicted to be in their observed ranges due to the broken $L_\mu - L_\tau$ symmetry. The second complex scalar was shown to be stable and became the dark matter candidate in our model. We showed that while the $Z_{\mu\tau}$ portal is ineffective for the parameters needed to explain the anomalous muon $(g-2)$ data, the correct dark matter relic abundance can easily be obtained from annihilation through the Higgs portal. Annihilation of the scalar dark matter in our model can also explain the Galactic Centre gamma ray excess observed by Fermi-LAT. We showed the predictions of our model for future direct detection experiments and neutrino oscillation experiments.

In (JHEP 1702 (2017) 123) we worked in the gauged $U(1)_{L_\mu - L_\tau}$ extension of the Standard Model (SM) which has a scalar FIMP DM candidate and can consistently explain the DM relic density bound. In addition, the spontaneous breaking of the $U(1)_{L_\mu - L_\tau}$ gauge symmetry gives an extra massive neutral gauge boson $Z_{\mu\tau}$ which can explain the muon $(g-2)$ data through its additional one-loop contribution to the process. Lastly, presence of three right-handed neutrinos enable the model to successfully explain the small neutrino masses via the Type-I seesaw mechanism. The presence of the spontaneously broken $U(1)_{L_\mu - L_\tau}$ gives a particular structure to the light neutrino mass matrix which can explain the peculiar mixing pattern of the light neutrinos.

DUNE (Deep Underground Neutrino Experiment) is a proposed long-baseline neutrino experiment in the US with a baseline of 1300 km from Fermi National Accelerator Laboratory (Fermilab) to Sanford Underground Research Facility, which will house a 40 kt Liquid Argon Time Projection Chamber (LArTPC) as the far detector. We worked on studying various new physics scenario at this experiment. In (JHEP 1608 (2016) 090) we simultaneously investigated source, detector and matter non-standard neutrino interactions at the proposed DUNE experiment. Our analysis was performed using a Markov Chain Monte Carlo exploring the full parameter space. We found that the sensitivity of DUNE to the standard oscillation parameters is worsened due to the presence of non-standard neutrino interactions. In particular, there are degenerate solutions in the leptonic mixing angle θ_{23} and the Dirac CP-violating phase δ_{CP}. We also computed the expected sensitivities at DUNE to the non-standard interaction parameters. We found that the sensitivities to the matter non-standard interaction parameters are substantially stronger than the current bounds (up to a factor of about 15). Furthermore, we discussed correlations between the source/detector and matter non-standard interaction parameters and found a degenerate solution in θ_{23}. Finally, we explored the effect of statistics on our results.

In (arXiv:1704.07269) we evaluated the impact of sterile neutrino oscillations in the so-called 3+1 scenario on the proposed long baseline experiments in USA and Japan. There are two proposals for the Japan experiment which are called T2HK and T2HKK. We showed the impact of sterile neutrino oscillation parameters on the expected sensitivity of T2HK and T2HKK to mass hierarchy, CP violation and octant of θ_{23} and compared it against that expected in the case of standard oscillations. We added the expected ten years data from DUNE and presented the combined expected sensitivity of T2HKK+DUNE to the oscillation parameters. We did a full marginalisation over the relevant parameter space and showed the effect of the magnitude of the true sterile mixing angles on the physics reach of these experiments. We showed that if one assumes that the source of CP violation is the standard CP phase alone in the test case, then it appears that the expected CP violation sensitivity decreases due to sterile neutrinos. However, if we give up this assumption, then the CP sensitivity could go in either direction. The impact on expected octant of θ_{23} and mass hierarchy sensitivity was shown to depend on the magnitude of the sterile mixing angles in a nontrivial way.

In (arXiv:1705.05820) we studied the consequences of invisible decay of neutrinos in the context of the DUNE experiment. We assumed that the third mass eigenstate is unstable and decays to a light sterile neutrino and a scalar or a pseudo-scalar. We obtained the bounds on the rest frame life time τ_3 normalized to the mass m_3 as $\tau_3/m_3 > 4.50 \times 10^{-11}$ s/eV at 90% C.L. for a normal hierarchical mass spectrum. We also found that DUNE can discover neutrino decay for $\tau_3/m_3 > 4.27 \times 10^{-11}$ s/eV at 90% C.L. We also studied the correlation between a non-zero τ_3/m_3 and standard oscillation parameters and found an interesting correlation in the appearance channel probability with the mixing angle θ_{23}. This alters the octant sensitvity of DUNE, favorably (unfavorably) for true θ_{23} in the lower (higher) octant. The effect of a decaying neutrino does not alter the hierarchy or CP discovery sensitivity of DUNE in a discernible way.

The DUNE experiment will also have a fine grained near detector for accurately measuring the initial fluxes. In (Phys.Lett. B764 (2017) 135-141) we showed that the energy range of the fluxes and baseline of the DUNE near detector is conducive for observing $\nu_\mu \to \nu_e$ oscillations of $\Delta m^2 \sim \mathrm{eV}^2$ scale sterile neutrinos, and hence can be effectively used for testing to very high accuracy the reported oscillation signal seen by the LSND and MiniBooNE experiments. We studied the sensitivity of the DUNE near detector to sterile neutrino oscillations by varying the baseline, detector fiducial mass and systematic uncertainties. We found that the detector mass and baseline of the currently proposed near detector at DUNE will be able to test the entire LSND parameter region with good precision. The dependence of sensitivity on baseline and detector mass was seen to give interesting results, while dependence on systematic uncertainties was seen to be small.

In (Eur.Phys.J. C77 (2017) no.5, 307) we studied the prospects of probing the sterile neutrino mixing with the magnetized Iron CALorimeter (ICAL) at the India-based Neutrino Observatory (INO), using atmospheric neutrinos as a source. The analysis was performed using the neutrino event generator NUANCE, modified for ICAL, and folded with the detector resolutions obtained by the INO collaboration from a full GEANT4 based detector simulation. A comparison was made between the results obtained from the analysis considering only the energy and zenith angle of the muon and combined with the hadron energy due to the neutrino induced event. A small improvement was observed with the addition of the hadron information to the muon. In the analysis we consider neutrinos coming from all zenith angles and the Earth matter effects were also included. The inclusion of events from all zenith angles improves the sensitivity to sterile neutrino mixing by about 35% over the result obtained using only down-going events. The improvement mainly stems from the impact of Earth matter effects on active-sterile mixing. The expected precision of ICAL on the active-sterile mixing is explored and allowed confidence level contours presented.

Publications:

1. Sandhya Choubey, *Atmospheric Neutrinos: Status and Prospects,* Nucl. Phys. **B908**, 235 (2016).

2. Sandhya Choubey, Dipyaman Pramanik, *Constraints on Sterile Neutrino Oscillations using DUNE Near Detector,* Phys. Lett. **B764**, 135, (2016).

3. Anirban Biswas, Sandhya Choubey, Sarif Khan, *Galactic gamma ray excess and dark matter phenomenology in a $U(1)_{B-L}$ model,* JHEP **1608**, 114, (2016).

4. Shiba Prasad Behera, Anushree Ghosh, Sandhya Choubey, V.M. Datar, D.K. Mishra, A.K. Mohanty, *Search for the sterile neutrino mixing with the ICAL detector at INO,* Eur. Phys. J. **C77**, 5, (2017).

5. Mattias Blennow, Sandhya Choubey, Tommy Ohlsson, Dipyaman Pramanik, Sushant K. Raut *A combined study of source, detector and matter non-standard neutrino interactions at DUNE,* JHEP **1608**, 090, (2016).

6. Anirban Biswas, Sandhya Choubey, Sarif Khan, *Neutrino Mass, Dark Matter and Anomalous Magnetic Moment of Muon in a $U(1)_{L_\mu - L_\tau}$ Model,* JHEP **1609**, 147, (2016).

7. Anirban Biswas, Sandhya Choubey, Sarif Khan, *FIMP and Muon $(g-2)$ in a $U(1)_{L_\mu - L_\tau}$ Model,* JHEP **1702**, 123, (2017).

Preprints:

1. Anirban Biswas, Sandhya Choubey, Sarif Khan, *Neutrino Mass, Leptogenesis and FIMP Dark Matter in a $\mathrm{U(1)_{B-L}}$ Model,* arXiv:1704.00819 [hep-ph].

2. Sandhya Choubey, Debajyoti Dutta, Dipyaman Pramanik, *Imprints of a light Sterile Neutrino at DUNE, T2HK and T2HKK,* arXiv:1704.07269 [hep-ph].

3. Sandhya Choubey, Srubabati Goswami, Dipyaman Pramanik, *A Study of Invisible Neutrino Decay at DUNE and its Effects on θ_{23} Measurement,* arXiv:1705.05820 [hep-ph].

Conference/Workshops Attended:

1. *Pheno1@IISERM*, India, April, 2016.

2. *International Neutrino Summer School 2016*, Vietnam, July, 2016.

3. *Invisibles16*, Italy, September, 2016.

Invited Lectures/Seminars:

1. *The Oscillating Neutrinos*, Invited talk at Pheno1@IISERM, IISER, Mohali, India, Mohali, April, 2016.

2. *Future Efforts of the Field* , Set of invited lectures at International Neutrino Summer School 2016, Recontres Du Vietnam, Quy Nhon, Vietnam, September, 2016.

Other Activities:

1. Member of the International Organising Committee, XIV International Workshop on Neutrino Telescopes, Venice, Italy, March 2017.

2. Served as the Convener Women's Grievances' Cell from April-June, 2016.

3. Served as the Chairperson Internal Complaints Committee/Women's Grievances' Cell from July 2016 to now.

Tapas Kumar Das

Research Summary:

The broad topics I have been working on are astrophysics of black holes (with specific emphasis on accretion astrophysics), analogue gravity phenomena, extra-galactic jets, nonlinear phenomena in strong gravity region, application of dynamical systems studies for large scale astrophysical fluid motions, and relativistic stellar models. Of late, I have started working on theory of traversable wormholes and time series analysis of astrophysical data to identify the chaotic behaviour in the light curves.

Publications:

1. Arif Shaikh, Md., Firdousi, Ivleena., & Das, Tapas K., *Relativistic sonic geometry for isothermal accretion in the Schwarzschild metric*, Classical and Quantum Gravity **34**, Issue 15, article id. 155008 (2017).

2. Bollimpalli, Deepika A., Bhattacharya, Sourav., & Das, Tapas K., *Perturbation of mass accretion rate, associated acoustic geometry and stability analysis*, New Astronomy **51**, 153, (2017).

3. Nag, Sankhasubhra., Sinha, Siddhartha., Ananda, Deepika B., & Das, Tapas K., *Influence of the black hole spin on the chaotic particle dynamics within a dipolar halo*, Astrophysics and Space Science **362**, Issue 4, article id.81, 8 pp., (2017).

Preprints:

1. Datta, Satadal., Arif Shaikh, Md., & Das, Tapas K., *Acoustic geometry obtained through the perturbation of the Bernoulli's constant*, New Astronomy (Under Review), arXiv:1612.07954 [gr-qc].

2. Tarafdar, Pratik., & Das, Tapas K., *Influence of matter geometry on shocked flows-I: Accretion in the Schwarzschild metric*, New Astronomy (Under Review), arXiv:1603.07932 [gr-qc].

3. Tarafdar, Pratik., Ananda, Deepika B., Nag, Sankhashubhra., & Das, Tapas K., *Influence of matter geometry on shocked flows-II: Accretion in the Kerr metric*, arXiv:1612.06882 [astro-ph.HE].

4. Islam, Safiqul., Datta, Satadal., & Das, Tapas K., *A parametric model to study the mass radius relationship of stars*, New Astronomy (Under Review), arXiv:1702.05171 [astro-ph.SR].

5. Majumder, Supriyo., Das, Tapas K., & Nag, Sankhasubhra., *Axially Symmetric Accretion of Fractal Medium onto Rotating Black Holes and the emergence of the Acoustic Manifold*, Monthly Notices of the Royal Astronomical Society (Under Review), arXiv:1702.01489 [astro-ph.HE].

6. Tarafdar, Pratik., & Das, Tapas K., *Influence of the geometric configuration of accretion flow on the black hole spin dependence of relativistic acoustic geometry*, arXiv:1705.00173 [gr-qc].

7. Konar, Chiranjib., Hardcastle, Martin., Croston, J. H., Jamrozy, Marek., Hota, Ananda, & Das, Tapas K., *Episodic radio galaxies and mode of accretion in them*, Submitted, Works reported in this paper has been presented (oral presentation) at the 35th annual meeting (held in March 2017 at Jaipur, India) of the Astronomical Society of India by Chiranjib Konar, who was my former post doc at HRI.

8. Tarafdar, Pratik., Ananda, Deepika B., Nag, Sankhashubhra., & Das, Tapas K., *Influence of disc geometry on transonic shocked accretion*, This work has been presented (poster presentation) at the 35th annual meeting (held in March 2017 at Jaipur, India) of the Astronomical Society of India by my student Pratik Tarafder , This poster has received the best poster award from the astronomical society of India.

Conference/Workshops Attended:

1. *Indo Canadian Winter School on Astronomy*, India, February, 2017, sponsored by the International Astronomical Union (IAU - The largest International Body of Professional Astronomers), funded by the University of Western Ontario, Canada. Students from eleven different countries attended this workshop.

   I was an invited speaker and was invited to serve as the panelist for the panel discussion 'Careers in Astronomy'.

2. *Nuclear & Astrophysics: Two Opposite Ends of Dimension*, West Bengal, January, 2017. I was invited to give a public lecture.

Visits to other Institutes:

1. Birla Science Centre, Hyderabad, India, February, 2017.

2. Vidyasagar University, West Bengal, India, January, 2017.

3. Centre for Theoretical Studies, Indian Institute of Technology, Kharagpur, West Bengal, India, January, 2017.

4. Several visits to S N Bose National Centre for Basic Sciences, Kolkata, India.

5. Several visits to Sarojini Naidu College, Kolkata, India (I have collaborators over there).

6. St. Xavier's College, Kolkata, India, March, 2017.

Invited Lectures/Seminars:

1. *Accretion onto astrophysical black holes*, a two lecture series, delivered at the Indo Canadian Winter School on Astronomy,, Hyderabad, February, 2017.

2. *Relativistic Astrophysics Around Massive Black Holes*, public lecture, as a part of the workshop Nuclear & Astrophysics: Two Opposite Ends of Dimension, Vidyasagar University, January, 2017.

3. *Black hole shadow imaging*, Colloquium at Centre for Theoretical Studies, Indian Institute of Technology, Kharagpur, January, 2017.

Other Activities:

1. Mentoring Project Students:
   (a) MS Ivleena Firdousi, September to November 2016. She authored a paper with me based on her work under my supervision.
   (b) Supriyo Majumder, December 2016. He authored a paper with me and my collaborator based on his work partially done under my supervision.
2. Thesis Examination:
   (a) Served as the viva voce examiner (external) for the thesis of a student from Savitribai Phule Pune University.
   (b) Served as the examiner of the Ph.D. thesis on the dynamics in the Rindler space submitted to some university in India (The exact title of the thesis and the name of the university have not been mentioned over here because of customary official confidentiality).
3. Teaching at HRI:
   (a) Mathematical Methods II (a one semester course) in 2016.
   (b) Astrophysics (a one semester course) in 2017.

AseshKrishna Datta

Research Summary:

In a work with my graduate student and physicists from another Institution in India, we explore the vacua of the Z_3-symmetric Next-to-Minimal Supersymmetric Standard Model (NMSSM) and their stability by going beyond the simplistic paradigm that works with a tree-level neutral scalar potential and adheres to some specific flat directions in the field space. Key effects are demonstrated by first studying the profiles of this potential under various circumstances of physical interest via a semi-analytical approach. The results thereof are compared to the ones obtained from a dedicated package like `Vevacious` which further incorporates the thermal effects to the potential. Regions of the phenomenological NMSSM (pNMSSM) parameter space that render the desired symmetry breaking (DSB) vacuum absolutely stable, long- or short-lived (in relation to the age of the Universe) under quantum/thermal tunneling are delineated. Regions that result in color and charge breaking (CCB) minima are also presented. It is demonstrated that light singlet scalars along with a light LSP (lightest supersymmetric particle) having an appreciable singlino admixture are compatible with a viable DSB vacuum and are much relevant for the collider experiments. *This work is now published in a journal.*

In another work with my graduate student and physicists from another Institution from abroad, we discuss the collider phenomenology of the model of Minimal Universal Extra Dimensions (MUED) at the Large hadron Collider (LHC). We derive analytical results for all relevant strong pair-production processes of two level 1 Kaluza-Klein partners and use them to validate and correct the existing MUED implementation in the Fortran version of the `PYTHIA` event generator. We also develop a new implementation of the model in the `C++` version of `PYTHIA`. We use our implementations in conjunction with the `CHECKMATE` package to derive the LHC bounds on MUED from a large number of published experimental analyses from Run-I at the LHC. *This work has been circulated on the arXiv.*

In yet another work with my graduate student, we have been studying for some time the phenomenon of spontaneous breakdown of charge in the MSSM and in the Z_3-symmetric NMSSM. The breakdown is triggered by the charged states of the Higgs doublets acquiring vacuum expectation values.

Publications:

1. Jyotiranjan Beuria, Arindam Chatterjee and AseshKrishna Datta, *Sbottoms of Natural NMSSM at the LHC,* JHEP 1608 (2016) 004.

2. Sabyasachi Chakraborty, AseshKrishna Datta, Katri Huitu, Sourov Roy and Harri Waltari, *Light top squarks in $U(1)_R$-lepton number model with a right handed neutrino and the LHC,* Phys.Rev. D93 (2016) no.7, 075005.

Preprints:

1. Jyotiranjan Beuria, AseshKrishna Datta, Dipsikha Debnath and Konstantin T. Matchev, *LHC Collider Phenomenology of Minimal Universal Extra Dimensions,*

arXiv:1702.00413 [hep-ph].

2. Jyotiranjan Beuria, Utpal Chattopadhyay, AseshKrishna Datta and Abhishek Dey, *Exploring viable vacua of the Z_3-symmetric NMSSM,* arXiv:1612.06803 [hep-ph].

Conference/Workshops Attended:

1. *PHENO1@IISERM (workshop)*, IISER, Mohali, India, April, 2016.

2. *Looking for BSM Physics (conference)*, IISc., Bangalore, India, December, 2016.

Visits to other Institutes:

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

2. Visited TIFR, Mumbai during May, 2016.

Invited Lectures/Seminars:

Invited to *"Particle Physics and the Cosmos" Galileo Galilei Institute Workshop* in Florence, Italy to be held during August-October, 2017.

Other Activities:

1. Serving as a member of the National Organising Committee for the 15th Workshop on High Energy Physics Phenomenology (WHEPP-15) to be held at IISER, Bhopal in December, 2017.

2. Served as a member of the National Advisory Board for the conference "Frontiers of Physics" held at the University of Burdwan, WB, India in March, 2017.

3. Supervising one student towards his Ph.D. degree (since December, 2013).

4. Serving the Doctoral Committee of several students.

5. Served as the referee for international journals.

6. Serving as a member of the NPS Monitoring Committee at HRI.

7. Adapting to an ever-evolving integrated environment for state-of-the-art simulation techniques aimed at present and future colliders.

Raj Gandhi

Research Summary:

The IceCube detector at the south pole has detected the highest energy neutrino events ever observed from astrophysical sources located at the farthest reaches of our universe. The events exhibit certain unexpected features which are not characteristic of the assumed nature of the emitting sources. We have examined the consequences of the premise that some of the events could represent the scattering of dark matter in the detector, and have shown how a combination of the expected neutrino fluxes and dark matter can explain the observed features. A second thrust of work has focussed on the effects of sterile neutrinos at long baselines. Our previous work showed (for the first time) that such effects were unexpectedly large. Continuing this line of inquiry, we examine how the the sensitivity of the flagship long baseline experiment, DUNE, to CP violation and the mass hierarchy is compromised by the presence of a sterile degree of freedom, the existence of which is hinted at by a number of short baseline experimental anomalies.

Publications:

1. A. Bhattacharya, R Gandhi, A. Gupta and S. Mukhopadhyay, *Boosted Dark matter and its implications for the features in IceCube HESE data,* JCAP **1705, no 05**, 002, (2017).

2. D. Dutta, R Gandhi, B. Kayser, and M. Masud , *Capabilities of long baseline experiments in the presence of a sterile neutrino,* JHEP **1611**, 122, (2016).

Conference/Workshops Attended:

1. *DUNE International Collaboration Meeting*, South Dakota, USA , May, 2016.

2. *International Conference on High Energy Physics (ICHEP)*, Chicago, USA, August , 2016.

3. *International Workshop on Frontiers in Electroweak Interactions of Leptons and Hadrons* , India , November, 2016.

Visits to other Institutes:

1. Fermilab, Chicago, USA, May-June, 2016.

2. Fermilab, Chicago, USA, Aug-Sep, 2016.

Invited Lectures/Seminars:

1. *The Impact of a sterile neutrino*, Invited Talk, DUNE International Collaboration Meeting, South Dakota, May, 2016.

2. *Sterile neutrinos at long baselines*, Invited Talk, International Conference on High Energy Physics, (ICHEP), Chicago, USA, August, 2016.

3. *CP Violation at long baselines in the presence of a sterile neutrino*, Plenary Talk, International Workshop on Frontiers in Electroweak Interactions of Leptons and Hadrons, Aligarh, India, November, 2016.

4. *The Highest Energy Neutrinos*, Invited Lecture, Special Interaction Meet for faculty and students of the Science Faculty, University of Lucknow, Lucknow, India, November, 2016.

Academic recognition/Awards:

- Neutrino Physics Center Fellow, Fermilab, 2016-2017.

Other Activities:

1. Member, Speakers committee, DUNE (Deep Underground Neutrino Experiment) International Collaboration), Fermilab.

2. Member, DUNE (Deep Underground Neutrino Experiment).

3. Currently Supervising three HRI Ph.D students and (informally) co-guiding one more at the University of Guwahati.

Dileep P. Jatkar

Research Summary:

This year I wrote three papers on three different topics. In the first paper, we studied N = 2 supersymmetric gauge theories with gauge group SU(2) coupled to fundamental flavours, covering all asymptotically free and conformal cases. We re-derived, from the conformal field theory perspective, the differential equations satisfied by omega deformed instanton partition functions. We confirmed their validity at leading order in one of the deformation parameters via a saddle-point analysis of the partition function. In the semi-classical limit we showed that these differential equations take a form amenable to exact WKB analysis. We computed the monodromy group associated to the differential equations in terms of deformed and Borel resummed Seiberg-Witten data. For each case, we studied pairs of Stokes graphs that are related by flips and pops, and show that the monodromy groups allow one to confirm the Stokes automorphisms that arise as the phase of the deformation parameter is varied. Finally, we related the Borel resummed monodromies with the traditional Seiberg-Witten variables in the semi-classical limit.

In the second paper, we studied patterns of quantum entanglement in systems of spins and ghost-spins regarding them as simple quantum mechanical toy models for theories containing negative norm states. We defined a single ghost-spin as in arXiv:1602.06505 [hep-th] as a 2-state spin variable with an indefinite inner product in the state space. We found that whenever the spin sector is disentangled from the ghost-spin sector (both of which could be entangled within themselves), the reduced density matrix obtained by tracing over all the ghost-spins gives rise to positive entanglement entropy for positive norm states, while negative norm states have an entanglement entropy with a negative real part and a constant imaginary part. However when the spins are entangled with the ghost-spins, there are new entanglement patterns in general. For systems where the number of ghost-spins is even, it is possible to find subsectors of the Hilbert space where positive norm states always lead to positive entanglement entropy after tracing over the ghost-spins. With an odd number of ghost-spins however, we found that there always exist positive norm states with negative real part for entanglement entropy after tracing over the ghost-spins.

In the third paper, we studied $N = (2, 4, 8)$ supersymmetric extensions of the three dimensional BMS algebra (BMS_3) with most generic possible central extensions. We found that N-extended supersymmetric BMS_3 algebras can be derived by a suitable contraction of two copies of the extended superconformal algebras. Extended algebras from all the consistent contractions are obtained by scaling left-moving and right-moving supersymmetry generators symmetrically, while Virasoro and R-symmetry generators are scaled asymmetrically. On the way, we find that the BMS/GCA correspondence does not in general hold for supersymmetric systems. Using the β-γ and the b-c systems, we constructed free field realisations of all the extended super-BMS_3 algebras.

Publications:

1. Sujay K. Ashok, Dileep P. Jatkar, Renjan R. John, Madhusudhan Raman, Jan Troost, *Exact WKB analysis of $\mathcal{N} = 2$ gauge theories* , JHEP **1607**, 115, (2016).

2. Nabamita Banerjee, Dileep P. Jatkar, Ivano Lodato, Sunil Mukhi, Turmoli Neogi, *Extended Supersymmetric BMS_3 algebras and Their Free Field Realisations* , JHEP **1611**, 059, (2016).

Preprints:

1. Dileep P. Jatkar, K. Narayan, *Entangled spins and ghost-spins,* arXiv:1608.08351 .

Conference/Workshops Attended:

1. *Indian Strings Meeting*, India, December, 2016.

2. *XXXI SERC-THEP School*, India, January, 2017.

Visits to other Institutes:

1. Indian Institute of Science and ICTS, Bengaluru, India, June, 2016.

2. Institute of Mathematical Sciences, Chennai, India, September, 2016

Invited Lectures/Seminars:

1. *Free field realisation of BMS algebra*, ICTS String Theory Seminar, ICTS, Bengaluru, June, 2016.

2. *Free field realisation of BMS algebra*, Group Seminar, Institute of Mathematical Sciences, Chennai, September, 2016.

Other Activities:

1. Taught a course on General Theory of Relativity in the August 2016 semester and Mathematical Methods II in the January 2017 semester at HRI.

2. Taught a course on "Scattering amplitudes" in the SERC-THEP school at the Kalyani University.

3. Convener of the physics graduate committee and the auditorium committee. Member of the office allocation committee.

Anshuman Maharana

Research Summary:

In the past year I have studied phenomenological implications of models of inflation constructed in string theory. I have focussed on two directions – the production of primordial magnetic fields and the dependence of inflationary predictions on moduli masses

We have analysed the production of primordial magnetic fields in inflationary models in type IIB string theory where the role of the inflaton is played by a Kähler modulus. We considered various possibilities to realise the Standard Model degrees of freedom in this setting and explicitly determined the time dependence of the inflaton coupling to the Maxwell term in the models. Using this we determined the strength and scale dependence of the magnetic fields generated during inflation. The usual "strong coupling problem" for primordial magnetogesis manifests itself by cycle sizes approaching the string scale, this appears in a certain class of fibre inflation models where the standard model is realised by wrapping D7-branes on cycles in the geometric regime.

The predictions for all the cosmological observables of any inflationary model depend on the number of e-foldings which is sensitive to the post-inflationary history of the universe. In string models the generic presence of light moduli leads to a late-time period of matter domination which lowers the required number of e-foldings and, in turn, modifies the exact predictions of any inflationary model. We have computed exactly the shift of the number of e-foldings in Kähler moduli inflation which is determined by the magnitude of the moduli initial displacement caused by vacuum misalignment and the moduli decay rates. We have found that the preferred number of e-foldings gets reduced from 50 to 45, causing a modification of the spectral index at the percent level.

Publications:

1. Luis Aparicio and Anshuman Maharana *Inflating Kähler Moduli and Primordial Magnetic Fields,* Phys. Lett. B **B768**, 46-51, (2017).

2. Michele Cicoli, Koushik Dutta, Anshuman Maharana and Fernando Quevedo, *Moduli Vacuum Misalignment and Precise Predictions in String Inflation,* JCAP **1608 no.08, 006**, (2016).

Conference/Workshops Attended:

1. *Conference on Aspects of String Phenomenology and Cosmology*, Italy, May, 2017.

Visits to other Institutes:

1. International Centre For Theoretical Physics, ICTP, Italy, May, 2017.

Invited Lectures/Seminars:

1. *Cosmological Moduli and Inflationary Predictions*, Conference on Aspects of String Phenomenology and Cosmology, ICTP, Trieste, May, 2017.

Other Activities:

1. Instructor for Quantum Mechanics II, January - May 2017

Pinaki Majumdar

Research Summary:

We have essentially completed work on the following problems: (i) the Mott transition on the molybdate and iridate models on a pyrochlore lattice, involving magnetic phase competition and spin-orbit coupling, respectively, (ii) the dynamical fluctuation spectrum in a bosonic model close to the superfluid-Mott transition, (iii) the phase diagram of spin-orbit coupled bosons, and (iv) an explanation of the quasiparticle interference pattern in the doped iron pnictides.

The work in progress include (i) The collective mode spectrum in gapped strongly correlated fermion systems, *e.g*, the magnetic fluctuations in the square and triangular lattice Mott insulators, and pairing fluctuations in clean and disordered superconductors. This is probed as a function of correlation strength and temperature, accessing regimes beyond the reach of standard random phase approximation. (ii) The nonequilibrium response of a Mott insulator to a large bias, leading to a voltage driven insulator-metal transition.

Publications:

1. Madhuparna Karmakar, Pinaki Majumdar *Anomalous pseudogap in population imbalanced Fermi superfluids* Eur. Phys. J. D (2016) 70: 220 .

2. Nyayabanta Swain, Rajarshi Tiwari, and Pinaki Majumdar *Mott-Hubbard transition and spin-liquid state on the pyrochlore lattice* Phys. Rev. B94, 155119 (2016).

3. Nyayabanta Swain and Pinaki Majumdar *Magnetic order and Mott transition on the checkerboard lattice* J. Phys. Condens. Matter 29 (2017) 085603 .

Preprints:

1. Nyayabanta Swain and Pinaki Majumdar *Mott transition and anomalous resistive state in the pyrochlore molybdates* arXiv:1606.06277v1

2. Nyayabanta Swain and Pinaki Majumdar *Ground state of the two orbital Hubbard model on the pyrochlore lattice with competing double exchange and superexchange interactions* arXiv:1610.00695v2

3. Sanjukta Paul, Ravindra Pankaj, Sudhakar Yarlagadda, Pinaki Majumdar, and Peter B. Littlewood *Giant magnetoelectric effect in pure manganite-manganite heterostructures* arXiv:1702.06302

Invited Lectures/Seminars:

1. *Mott transition in the pyrochlores*, Indo-US Conference, SNBNCBS Kolkata, Jan 2017.

2. *Quantum many body theory with fluctuating classical fields*, 10th Anniversary Meeting of IISER, IISER Kolkata, Jan 2017.

Other Activities:

1. Organised a School on 'Nonequilibrium quantum many body theory' at HRI, Nov 2016.

2. Co-organised a meeting on 'Low dimensional quantum systems' at HRI, Feb 2017.

3. Organised a two day lecture series on 'Fluid mechanics, dynamical systems and statistical physics' at HRI, March 2017.

Biswarup Mukhopadhyaya

Research Summary:

It is a challenge to test at the Large Hadron Collider (LHC) whether the Higgs-tau-tau interaction has a CP-violating component. It was shown using an intensive tau-polarisation analysis that this is best done in the vector boson fusion channel, where a CP-violating phase greater than 25^o can be probed in the high luminosity run.
(with Tao Han, S. Mukhopadhyay and Y. Wu)

A warped geometry scenario with one extra spacelike dimension admits of Chern-Simons interactions involving the standard model gauge bosons and an axion arising from spacetime torsion. It was demonstrated that such an axion of mass $\leq$ TeV can be produced at the LHC and generate diphoton signals that can be detectable in experiments.
(with N. Chakrabarty and S. SenGupta)

Additional scalar bosons which may have some role in electroweak symmetry breaking are often envisioned. It was shown how a scenario with such additional scalars may lead to LHC signals that can correlate dark matter signals, Higgs p_T-distribution, dilepton data and a few other things.
(with S. Buddenbrock, N. Chakrabarty, A. Cornell, T. Mandal, D. Kar, B. Mellado and R. Reed)

A supersymmetric (SUSY) scenario with a right sneutrino dark matter candidate may lead to unconventional LHC signals comprising stable charged tracks. it was shown such cases may cause a revival of models based on minimal supergravity, and the consequent experimental issues were examined.
(with S. Banerjee, G. Belanger and P. Serpico)

The vacuum stability issue of the electroweak theory, together with the requirement of high-scale perturbative unitarity favours two-Higgs doublet models (2HDM) slightly more than the minimal standard model. Detailed collider signals of 2HDM spectra that fall in this favoured region were predicted.
(with N. Chakrabarty)

The present data on the scalar boson thought of as the Higgs particle keep room for effective interactions with standard model particles. An investigation showed that some such effective interactions can lead to the enhancement of LHC signals consisting of two b-jets and a hard photon.
(with S. Dwivedi and S. Mondal)

Publications:

1. Avinanda Chaudhuri, Biswarup Mukhopadhyaya, *CP -violating phase in a two Higgs triplet scenario: Some phenomenological implications,* Phys. Rev. **D93**, 093003, (2016).

2. Nabarun Chakrabarty, Biswarup Mukhopadhyaya, *High-scale validity of a two Higgs doublet scenario: metastability included,* Eur. Phys. J. **C77** , 153, (2017).

3. Siddharth Dwivedi, Dilip Kumar Ghosh, Ambresh Shivaji, Biswarup Mukhopadhyaya, *Distinguishing CP-odd couplings of the Higgs boson to weak boson pairs,* Phys. Rev **D93**, 115039, (2016).

4. Shankha Banerjee, Genevieve Belanger, Biswarup Mukhopadhyaya, Pasquale D. Serpico *Signatures of sneutrino dark matter in an extension of the CMSSM,* JHEP **1607**, 098, (2016).

5. Nabarun Chakrabarty, Biswarup Mukhopadhyaya, Soumitra SenGupta, *Diphoton signals via Chern-Simons interactions in a warped geometry scenario,* Phys. Rev. **D95**, 015007, (2017).

6. S. Buddenbrock, N. Chakrabarty, A. Cornell, T. Mandal, D. Kar, B. Mellado, Biswarup Mukhopadhyaya, R. Reed, *Phenomenological signatures of additional scalar mosons at the LHC,* Eur. Phys. J. **C76**, 580, (2017).

Preprints:

1. A. Choudhury, A. Kundu, Biswarup Mukhopadhyaya, *The role of leptonic cascades in $B_c \longrightarrow B_s$ at the LHC,* arXiv:1606.08402[hep-ph].

2. Tao Han, S. Mukhopadhyay, Biswarup Mukhopadhyaya, Y. Wu *Measuring the CP-property of Higgs coupling to tau leptons at the LHC,* arXiv:1612.000413[hep-ph].

3. Siddharth Dwivedi, Subhadeep Modal, Biswarup Mukhopadhyaya, *Exploring anomalous $hb\bar{b}$ and $hb\bar{b}\gamma$ couplings on the context of the LHC and an e+e- collider ,* arXiv:1702.06003[hep-ph]

4. Nabarun Chakrabarty, Biswarup Mukhopadhyaya, *High =scale validity of of a two-Higgs doublet scenario: predicting collider signals,* arXiv:1702.08268[hep-ph].

Conference/Workshops Attended:

1. *Pheno-2016*, Pittsburgh, USA, May, 2016.

2. *Workshop on collider physics*, IIT, Guwahati, March, 2017.

Visits to other Institutes:

1. University of Pittsburgh, Pittsburgh, USA, April-May, 2016.

2. Indian Association for the Cultivation of Science, June, 2016.

3. Korea Institute of Advanced Study, Seoul, Korea, September-October, 2016.

4. NIT, Jalandhar, October, 2016.

5. University of Calcutta, January, 2017.

6. Name of the institute, place, Country, month, year.

Invited Lectures/Seminars:

1. *The vacuum stability issue: can it be Higgses and nothings else?* Institute of Mathematical Sciences, Chennai, April, 2016.
2. *Particles, Accelerators, Symmetries*, Presidency University, Kolkata, April, 2016.
3. *Left-sneutrino LSP and same-sign trleptons at the LHC*, Pheno-16, Pittsburgh, USA, May, 2016.
4. *The messiah of mass and message about more*, Symposium, University of Calcutta, Kolkata, June, 2016.
5. *The messiah of mass and message about more*, HRI symposium, August, 2016.
6. *The messiah of mass: an answer that becomes questions*, Colloquium, Indian Association for the Cultivation of Science, Kolkata, September, 2016.
7. *Heaven on earth: some SUSY dark matter scenarios and their collider signals*, Korea Institute of Advanced Study, Seoul, Korea, September, 2016.
8. *A pedagogical introduction to dark matter*, NIT, Jalandhar, October, 2016.
9. *Five years with the Higgs boson*, Invited public lecture at Banaras Hindu University, Varanasi, November, 2016.
10. *The messiah of mass and message about more*, Jogamaya College, Kolkata, November, 2016.
11. *Supersymmetry in the context of dark matter*, Set of lectures delivered at National Centre for Radio Astrophysics, Pune, January, 2017.
12. *Some unusual dark matter scenarios*, Indian Association for the Cultivation of Science, Kolkata, January, 2017.
13. *The role of symmetry in physics* , Amity University, Lucknow, February, 2017.
14. *Physics and symmetries*, Science day lecture at Allahabad Museum, February, 2017.
15. *Physics and symmetries*, Indian Institute of technology, Guwahati, March, 2017.

Academic recognition/Awards:

- DAE-HBNI Distinguished Faculty Award, 2015

Other Activities:

1. Taught classical mechanics in the HRI graduate programme.
2. Headed the regional Centre for Accelerator-based Particle Physics (RECAPP) at HRi. Organised the set-up of a new cluster computing facility at RECAPP, a facility that has been used outside HRI by researchers at University of Delhi, Aligarh Muslim University, IIT, Guwahati, IIT, Gandhinagar, IISER, Kolkata etc. .

Satchidananda Naik

Research Summary:

Non-Perturbative evaluation of Adler Function in SUSY Yang-Mills theories :
For $\mathcal{N} = 1$ Supersymmetric Yang Mills theories Current- Current correlation function

is calculated to all orders of perturbation which eventually gives rise to exact evaluation of Adler function. The Adler function is extremely important to get the hints of experimental signature of Supersymmetry. However for $\mathcal{N} = 2$ Supersymmetric theories in the strong coupling region non-perturbative effects dominate and perturbatve evaluation of the two point correlation function is insufficient to get a fruitful result. In this context we use non-pertubative methods to evaluate this.

Publications:

1. S Naik, *Non-Perturbative corrections to Adler Function for SUSY Yang Mills theories* (Presented in Conferences ; to appear soon)

2. S Naik, *Problems with Formulation of Covariant String Field theory with Ramond Fermions and possible remedies*(Presented in Conferences ; to appear soon)

Conference/Workshops Attended:

1. *Workshop on Quantum Field theory and Black hole*, BHU , 2016

2. *International Strings Meeting 2016*, IISER Pune, India, December, 2016.

Invited Lectures/Seminars:

1. *A series of Lectures given on Large N gauge theories*, BHU, Varanasi,2016.

2. *Exact Adler Function for Susy Gauge theories* HRI, Allahabad, July, 2016.

Courses given:

1. *Quantum Field theory II* , from January- May 2016.

2. *Advanced Electrodynamics*,January- May 2017

3. *Atomic and Molecular Physics* July- Dec 2017

Other activities

1. Supervising a Student for his Thesis.

2. Supervising several students for their reading special projects.

G. Venketeswara Pai

Research Summary:

My research focuses on strongly correlated electron systems. Specific problems include the effect of geometric frustration on the Holstein-Hubbard model at half-filling and the onset and evolution of superconductivity in a model of percolation. Recently, we have started working on correlated superconductivity in topological systems.

Preprints:

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

Visits to other Institutes:

1. Department of Physics, Cochin University of Science and Technology, India, November 2016

Invited Lectures/Seminars:

1. *Correlations and Lattice Coupling in Electron Systems*
   Physics Colloquium, Department of Physics, Cochin University of Science and Technology, India, November 2016

2. *Qualitative Methods in Physics*
   A set of lectures, Department of Physics, Sree Kerala Varma College, Thrissur, India, November 2016

Other Activities:

1. Taught a graduate level course, Statistical Mechanics, during Jan-May 2017

2. External member, Thesis evaluation committee, Indian Institute of Science Education and Research, Thiruvananthapuram, 2016

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

Tribhuvan Prasad Pareek

Research Summary:

In condensed matter systems charge, a scalar quantity and spin being an intrinsically quantum spinor both are carried by electronic degrees of freedom. The coupled dynamics of charge and spin leads to various interesting and intricate phenomena such as topological insulators etc. The coupled evolution of charge and spin is essentially a non-perturbative problem and as such requires paradigam shift compared to conventional perturbative studies. Towards a first step we had developed a formal non-perturbative density matrix theory to study such peoblem. In continuation of this approach we are studying toplogical eveolution of density matrices both numerically as well mathematically. Using this various toplogical featuers as well toplogical transport are being studied

Preprints:

1. Tribhuvan Prasad Pareek)*Topological evolution of density matrices and emergent topological liquids: manuscript under preparation*

Other Activities:

1. I am member of various adminstrative and acdemic committies of institute.
2. I have taught Mathematical Methods I course to graduate students.

Arun Kumar Pati

Research Summary:

Uncertainty Relations for Quantum Coherence: Coherence of a quantum state intrinsically depends on the choice of the reference basis. A natural question to ask is the following: if we use two or more incompatible reference bases, can there be some trade-off relation between the coherence measures in different reference bases? We show that the quantum coherence of a state as quantified by the relative entropy of coherence in two or more noncommuting reference bases respects uncertainty like relations for a given state of single and bipartite quantum systems. In the case of bipartite systems, we find that the presence of entanglement may tighten the above relation. Further, we find an upper bound on the sum of the relative entropies of coherence of bipartite quantum states in two noncommuting reference bases. Moreover, we provide an upper bound on the absolute value of the difference of the relative entropies of coherence calculated with respect to two incompatible bases.

Tighter Uncertainty and Reverse Uncertainty Relations: We prove a few novel state-dependent uncertainty relations for product as well the sum of variances of two incompatible observables. These uncertainty relations are shown to be tighter than the Roberson-Schrödinger uncertainty relation and other ones existing in the current literature. Also, we derive state dependent upper bound to the sum and the product of variances using the reverse Cauchy-Schwarz inequality and the Dunkl-Williams inequality. Our results suggest that not only we cannot prepare quantum states for which two incompatible observables can have sharp values, but also we have both, lower and upper limits on the variances of quantum mechanical observables at a fundamental level.

Spookyfying Quantum Information is Impossible: Classical information encoded in composite quantum states can be completely hidden from the reduced subsystems and may be found only in the correlations. Can the same be true for quantum information? If quantum information is hidden from subsystems and spread over quantum correlation, we call it as spookyfying of quantum information. We show that while this may still be true for some restricted sets of non-orthogonal quantum states, it is not possible for arbitrary quantum states. This result suggests that quantum qubit commitment – a stronger version of the quantum bit commitment is not possible in general. Our findings may have potential applications in secret sharing and future quantum communication protocols.

Exact master equation for a spin interacting with a spin bath: An exact canonical master equation of the Lindblad form is derived for a central spin interacting uniformly with a sea of completely unpolarized spins. The Kraus operators for the dynamical map are also derived. The non-Markovianity of the dynamics in terms of the divisibility breaking of the dynamical map and increase of the trace distance fidelity between quantum states is shown. Moreover, it is observed that the irreversible entropy production rate is always negative (for a fixed initial state) whenever the dynamics exhibits non-Markovian behavior. In continuation with the study of witnessing non-Markovianity, it is shown that the positive rate of change of the purity of the central qubit is a faithful indicator of the non-Markovian information back flow. Given the experimental feasibility of measuring the purity of a quantum state, a possibility of experimental demonstration of non-Markovianity and the negative irreversible entropy production rate is addressed. This gives the present work considerable practical importance for detecting the non-Markovianity and the negative irreversible entropy production rate.

Resource Theory of Special Antiunitary Asymmetry: We propose the resource theory of a special antiunitary asymmetry in quantum theory. The notion of antiunitary asymmetry, in particular, PT-asymmetry is different from the usual resource theory for asymmetry about unitary representation of a symmetry group, as the operator is an antiunitary operator with being any self-inverse unitary and being the time-reversal operations. Here, we introduce the PT-symmetric states, PT-covariant operations and PT-asymmetry measures. For single qubit system, we find duality relations between the PT-asymmetry measures and the coherence. Moreover, for two-qubit states we prove the duality relations between the PT-asymmetry measures and entanglement measure such as the concurrence. This gives a resource theoretic interpretation to the concurrence which is lacking till today. Thus, the -asymmetry measure and entanglement can be viewed as two sides of an underlying resource. Finally, the PT-symmetric dynamics is discussed and some open questions are addressed.

Coherence and Entanglement Monogamy in the Grover Search: Grover's search algorithm is the optimal quantum algorithm that can search an unstructured database quadratically faster than any known classical algorithm. The role of entanglement and correlations in the search algorithm have been studied in great detail and it is known that entanglement between the qubits is necessary to gain a quadratic speedup, for pure state implementation of the Grover search algorithm. Here, we systematically investigate the behavior of quantum coherence and monogamy of entanglement in the discrete analogue of the analog analogue of Grover search algorithm. The analog analogue of Grover search is a continuous time quantum algorithm based on the adiabatic Hamiltonian evolution that gives a quadratic speedup, similar to the original Grover search algorithm. We show that the decrease of quantum coherence, quantified using various coherence monotones, is a clear signature of attaining the maximum success probability in the analog Grover search. We also show that for any two qubit reduced density matrix of the system, the concurrence evolves in close vicinity to the increasing rate of success probability. Furthermore, we show that the system satisfies a n-party monogamy inequality for arbitrary times, hence bounding the amount of n-qubit entanglement during the quantum search.

Mutual Uncertainty and Strong Sub-Additivity: Using the variance based uncertainty, we introduce a new concept called as the mutual uncertainty between two observables in a given quantum state which enjoys similar features like the mutual information for two random variables. Further, we define the conditional uncertainty and show that conditioning on more observable reduces the uncertainty. Given three observables, we prove a 'strong sub-additivity' theorem for the conditional uncertainty under certain condition. As an application, we show that for pure product two-qubit states, the mutual uncertainty is bounded by $2-\sqrt{2} = 0.586$ and if it is greater than this value then it indicates that the state is entangled. For mixed two-qubit states, we prove that the mutual uncertainty for product, classical-classical, and classical-quantum state also takes a universal value 0.586. We also show how to detect quantum steering using the mutual uncertainty between two observables. Our results may open up a new direction of exploration in quantum theory and quantum information using the mutual uncertainty, conditional uncertainty and the strong sub-additivity for multiple observables.

Publications:

1. L. Zhang, U. Singh, A. K. Pati,
   Average Subentropy and Coherence of Random Mixed Quantum States,
   Ann. of Phys. **377**, 125 (2017).

2. S. Bhattacharya, A. Misra, C. Mukhopadhyay, A. K. Pati,
   Exact Master Equation for a Spin Interacting with a Spin Bath: Non-Markovianity and Negative Entropy Production Rate,
   Phys. Rev. A **95**, 012122 (2017).

3. J. L. Chen, C. Ren, C. Chen, X. J. Ye and A. K. Pati,
   Bell's Nonlocality Can be Detected by the Violation of Einstein-Podolsky-Rosen Steering Inequality,
   (NATURE) Scientific Reports, **6**, 39063 (2016).

4. S. Bagchi and A. K. Pati,
   Uncertainty Relations for General Unitary Operators,
   Phys. Rev. A **94**, 042104 (2016).

5. N. Shukla, A. K. Pati,
   Pancharatnam Phase Deficit can Detect Macroscopic Entanglement,
   Euro. Phys. Lett. **115**, 40002 (2016).

6. P. Agrawal, Sk. Sazim, I. Chakrabarty and A. K. Pati,
   Local, Nonlocal Quantumness and Information Theoretic Measures,
   Int. J. of Quant. Inf. **14**, 1640034 (2016).

7. J. L. Chen, H. Y. Su, Z. P. Xu, A. K. Pati,
   Sharp Contradiction for Local Hidden-State Model in Quantum Steering,
   (NATURE) Scientific Reports **6**, 32075 (2016).

8. U. Singh, A. K. Pati, M. N. Bera,
   Uncertainty Relations for Quantum Coherence,
   Mathematics **4**, 47 (2016).

9. M. J. W. Hall, A. K. Pati, J. Wu,
   Products of Weak Values: Uncertainty Relations, Complementarity and Incompatibility, Phys. Rev. A **93**, 052118 (2016).

10. A. Misra, U. Singh, S. Bhattacharya, A. K. Pati,
    Energy Cost of Creating Quantum Coherence,
    Phys. Rev. A **93**, 052335 (2016).

Preprints:

1. N. Anand and A. K. Pati,
   Coherence and Entanglement Monogamy in the Discrete Analogue of Analog Grover Search,
   arXiv:1611.04542 (2016).

2. K. Bu, H. Fan, A. K. Pati, J. Wu,
   Resource Theory of Special Antiunitary Asymmetry,
   arXiv:1610.09646 (2016).

3. K. Modi, A. K. Pati, A. Sen De, U. Sen,
   Spookyfying Quantum Information is Impossible,
   arXiv:1608.01695.

4. D. Mondal, S. Bagchi, A. K. Pati,
   Tighter Uncertainty and Reverse Uncertainty Relations,
   arXiv:1607.05522.

5. A. K. Pati,
   Measuring Electromagnetic Vector Potential via Weak Value,
   arXiv:1602.04140.

6. S. Bhattacharya, S. Banerjee, A. K. Pati,
   Effect of non-Markovianity on the Dynamics of Coherence, Concurrence and Fisher Information,
   arXiv:1601.0474

Conference/Workshops Attended:

1. International conference on "Concepts and Paradoxes in a Quantum Universe", in honor of Prof. Yakir Aharonov held at Perimeter Institute for Theoretical Physics in Waterloo, Canada from June 20-24, 2016.

2. Workshop on Quantum Information and Computation at CSIR-NPL, New Delhi on August 19, 2016.

3. International Conference "Quantum Foundations 2016" held from October 17-21, 2016 at the National Institute of Technology in Patna, India.

4. National Seminar on "Solid State Devices for Quantum Computing Applications" organized by Solid State Physics Laboratory, DRDO, New Delhi on 26th Nov. 2016.

Visits to other Institutes:

1. Visited Prof. Tabish Qureshi at Centre for Theoretical Physics, Jamia Millia Islamia New Delhi during December 22-30, 2016 as Honorary Adjunct Professor.

2. Visited Prof. P. Agrawal, Institute of Physics during April 12 - May 25, 2016.

3. Visited Prof. S. Misra, Department of Physics, Berhampur University, Odisha during December 7-10, 2016 on the occasion of Golden Jubilee celebration.

Invited Lectures/Seminars:

1. Invited speaker in International conference on "Concepts and Paradoxes in a Quantum Universe", in honor of Prof. Yakir Aharonov held at Perimeter Institute for Theoretical Physics in Waterloo, Canada from June 20-24, 2016.

2. Invited speaker at one day workshop on Quantum Information and Computation at CSIR-NPL, New Delhi on August 19, 2016.

3. Invited Speaker in International Conference "Quantum Foundations 2016" held from October 17-21, 2016 at the National Institute of Technology in Patna, India.

4. Invited as a Plenary Speaker at the Quantum and Nano Computing Advanced School (QANSAS 2015) scheduled from Nov. 23-Nov. 26, 2016 in DEI, Dayalbagh Agra.

5. Invited speaker in National Seminar on "Solid State Devices for Quantum Computing Applications" organized by Solid State Physics Laboratory, DRDO, New Delhi on 26th Nov. 2016.

6. Invited as a distinguished Alumni of Department of Physics, Berhampur University, Odisha to deliver a seminar on dated 07.12.16 on the occasion of Golden Jubilee celebration.

7. Invited speaker at International Conference on "Complex Quantum Systems" held during Feb. 20-23, 2017 at Bhabha Atomic Research Centre, Mumbai.

Academic recognition/Awards:

- Honorary Professor in the Center for Theoretical Physics, Jamia Milia University, New Delhi.

- The discovery of Bell's nonlocality detection by the violation of Einstein-Podolsky-Rosen Steering Inequality is highlighted in 31st January 2017 issue of NATURA ASIA.
  Physicists 'steer' out of quantum mystery
  (http://www.natureasia.com/en/nindia/article/10.1038/nindia.2017.13)

Other Activities:

1. Invited to Inaugural event and Panel discussion for the Nobel Prize Series-2017, India held at Ahemadabad, Gujrat during Jan 9-10, 2017. Several Nobel laureates, eminent scientists and Internationally eminent personalities have been invited to this event in the august presence of Honorable Prime Minister of India.

2. Invited as a speaker and role model to one of the largest National Level Technical Festival FootPrints X7, to be held at M.S University, Baroda Faculty of Technology and Engineering (FoTE), the Maharaja Sayajirao University of Vadodara (MSU), Gujarat, INDIA during 24-26th February, 2017. In the past, Nobel laureates and several Internationally eminent personalities have been invited to this event. (Though could not attend due to unavoidable reason.)

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

4. Evaluated Ph.D. thesis from IIT, Roorkee and IISER, Mohali.

5. Four students have submitted PhD thesis and two students are continuing PhD in the area of Quantum Information at HRI, Allahabad.

Santosh Kumar Rai

Research Summary:

My research has been focussed on beyond the Standard Model (SM) of particle physics and their collider signals at LHC and a future proposed electron-proton machine (LHeC). My work also included a study on possible interpretation to a diphoton excess observed by the LHC experiment. I worked on signals for heavy neutrinos in left-right gauge extended model and new possibilities in its supersymmetric extension, as well as on abelian extensions to the SM motivated by E_6 grand unified model and their implications in collider experiments.

In models predicting heavy SM singlet neutrinos and their studies at LHeC, we consider the production of a heavy neutrino and its possible signals at the Large Hadron-electron Collider (LHeC) in the context of an inverse-seesaw model for neutrino mass generation. The inverse seesaw model extends the SM particle content by adding two neutral singlet fermions for each lepton generation. It is a well motivated model in the context of generating non-zero neutrino masses and mixings. The proposed future LHeC machine presents us with a particularly interesting possibility to probe such extensions of the SM with new leptons due to the presence of an electron beam in the initial state. We showed that the LHeC will be able to probe an inverse scenario with much better efficacy compared to the LHC with very nominal integrated luminosities as well as exploit the advantage of having the electron beam polarized to enhance the heavy neutrino production rates.

We also successfully defended and replied to a "Comment" against our earlier work [S. Mondal and S.K. Rai, Phys. Rev. D 93, 011702 (2016).] which was based on a presumptive and incorrectly chosen large value of charge-flip probability. We addressed the concerns of the commenter and showed why the values chosen and the estimates of the background cross section given in the Comment become irrelevant when folded in with expected numbers for the efficiency provided by an analysis done by the CMS Collaboration for a heavy Majorana neutrino search after proper event selection criteria are set for the final states.

In the supersymmetric extension of left-right theory, we showed that right-handed sneutrinos are natural components of left-right symmetric supersymmetric models where the gauge sector is extended to include right-handed weak interactions. Unlike in other models where right-handed sneutrinos are gauge singlets, here the right sneutrino is part of a doublet and could be a dark matter candidate whose annihilation proceeds via gauge interactions. We investigated this possibility, and found that relic density, low-energy observable and direct supersymmetry search constraints can be satisfied when the lightest supersymmetric particle is a right-handed sneutrino. through benchmark choices of parameters for left-right supersymmetric realizations where either a sneutrino or a neutralino is the lightest superpartner, we studied the LHC signals arising through resonant right-handed slepton production via a W_R gauge-boson exchange that lead to final states enriched in leptons, additionally containing a large amount of missing transverse momentum, and featuring a low jet multiplicity. We highlighted that such a resonant production would boost the chances of discovering these weakly interacting supersymmetric particles for a mass range extending beyond 1 TeV already with a luminosity of 100 fb1. Finally, we compared sneutrino versus neutralino scenarios, and commented on differences with other sneutrino dark matter models.

Publications:

1. M. Frank, B. Fuks, K. Huitu, Santosh Kumar Rai and H. Waltari, *Resonant slepton production and right sneutrino dark matter in left-right supersymmetry,* JHEP **1705**, 015 (2017).

2. S. Mondal and Santosh Kumar Rai, *Reply to Comment on Polarized window for left-right symmetry and a right-handed neutrino at the Large Hadron-Electron Collider,* Phys. Rev. D **93**, no. 11, 118702 (2016).

3. S. Mondal and Santosh Kumar Rai, *Probing the Heavy Neutrinos of Inverse Seesaw Model at the LHeC,* Phys. Rev. D **94**, no. 3, 033008 (2016).

Preprints:

1. K. Das, T. Li, S. Nandi and Santosh Kumar Rai, *A new proposal for diphoton resonance from E_6 motivated extra $U(1)$,* [arXiv:1607.00810 [hep-ph]].

2. J. Dutta, P. Konar, S. Mondal, B. Mukhopadhyaya and Santosh Kumar Rai, *Search for a compressed supersymmetric spectrum with a light Gravitino,* (in preparation).

Conference/Workshops Attended:

1. *LIA THEP/ CEFIPRE INFRE-HEPNET Meeting*: CHEP, IISc. Bengaluru, India, May, 2016.

2. *750 GeV excess under scrutiny* : ICTS, Bengaluru, India May, 2016.

3. *Looking for BSM Physics*: CHEP, IISc., Bengaluru, India, December, 2016.

4. *SERC THEP Main School:* University of Kalyani, Kalyani, West Bengal, January, 2017.

Visits to other Institutes:

1. University of Helsinki and Helsinki Institute of Physics, Helsinki, Finland, May-June 2016.

Invited Lectures/Seminars:

1. *Renormalization of the Standard Model:* Invited Guest faculty (Tutor), SERC THEP Main School, University of Kalyani, Kalyani, West Bengal, January, 2017.

2. *Revisiting Compressed Supersymmetry at LHC:*
Helsinki Institute of Physics & University of Helsinki, Finland; May 31, 2016.

3. *750 GeV diphoton excess in a $U(1)$ hidden symmetry model:* 750 GeV excess under scrutiny, ICTS, Bengaluru, India, May 2016.

4. *Wishing Beyond the LHC*: Looking for BSM Physics, CHEP, Indian Institute of Sciences, Bengaluru, India; December 2016.

Other Activities:

1. Teaching course at HRI titled *Particle Physics*, Jan-April, 2017.

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

3. Member, Library Committee, VSP Committee and Horticulture Committee (Convener) 2016-2017.

Sumathi Rao

Research Summary:

During the period, April 2016-March 2017, we continued our work from the previous couple of years on topological phases of matter.

We had earlier studied the Josephson current in a time-reversal Weyl semi-metal, sandwiched between s-wave superconductors which showed periodic oscillations as a function of the distance between the Weyl nodes. We finished the analysis we had started on studying the Josephson current in inversion symmetry breaking, time-reversal symmetry preserving Weyl semimetals and showed how zero-pi transitions in these materials could be tuned by shining light. We are also finishing our analysis of the Weyl semi-metal-insulator-superconductor junctions and have obtained interesting results on the interplay of the two scales provided by the scale of symmetry breaking and the barrier strength. We have shown consistency of the results from a scattering matrix approach as well as a Green's functions approach and have given a theoretical explanation of the oscillations.

We continued with the investigation of this model and showed that even when the Weyl semi-metal is sandwiched between normal metals, electrical transport across the metal shows oscillations which can be interpreted as interference patterns produced in an anisotropic momentum space double-slit interferometer. We are also trying to understand the spin textures around the Weyl nodes and looking for experimental signatures which could see a difference, perhaps using ferromagnetic leads.

We have also been continuing our work on silicene and have finished the work on trying to develop the Brilloiun-Wigner (BW) theory for driven systems and obtained interesting phase diagrams. We have also shown that for the high frequency limit, the BW theory works quite well, by comparing it with an exact calculation. We are now in the process of finishing up the computation at low frequencies, where we compute the new topological invariants C_π as well for the spin up and spin down components.

We are continuing our work on charge pumping in an Aharanov-Bohm geometry. We have contrasted charge pumping through a Majorana bound state with charge pumping through an Andreev bound state as well as through a resonant level, and tried to understand the differences in terms of explicit processes.

We are also working on the chiral edge modes of a Quantum Hall system. It is well-known that when the edge potential is softened, it undergoes spontaneous reconstruction due to charging effects. But we have looked for effects which are driven by exchange effects. We have shown that the ordering of the edge modes at $\nu = 3$ switches abruptly as the edge potential is made softer, while the ordering in the bulk remains intact. We have demonstrated that this phenomenon is robust, and has many verifiable experimental signatures in transport.

We have written lecture notes on abelian and non-abelian anyons, based on lectures given at the SERC school on topology in condensed matter systems held in December 2015.

Finally, we have started studying topics in the field of topological quantum computation. We have worked on a model related to the Kitaev chain in one dimension, but including nearest neighbour repulsive interactions. Using a mapping to the non-interacting Kitaev model, we have computed quantities like entanglement entropy and entanglement spectrum and also other related quantities like concurrence and discord.

Publications:

1. Fingerprints of Majorana bound states in Aharanov-Bohm geometry (with Krashna Mohan Tripathi and Sourin Das), Phys. Rev. Lett. **116**, 166401 (2016).

2. Slave fermion formalism for the tetrahedral spin chain (with Priyanka Mohan), Eur. Phys. J. **B 89**, 206 (2016).

3. Weyl semi-metals; a short review, cond-mat/1603.02821, Jnl of Indian Institute of Science, 96(2), 145 (2016).

4. Brillouin-Wigner theory for Floquet topological phase transitions in spin-orbit coupled materials (with Priyanka Mohan, Ruchi Saxena and Arijit Kundu), Phys. Rev. **B94**, 235419 (2016).

Preprints:

1. Introduction to abelian and non-abelian anyons, cond-mat/1610.09260, lectures given at the SERC school on 'Topology and condensed matter physics', held in Kolkata, Nov 23-Dec 12, 2015, to be published by Hindustan Book Agency.

2. Zero-pi Josephson current transitions in irradiated Weyl semi-metals (with Udit Khanna and Arijit Kundu), cond-mat/1703.01312 (accepted for publication in Phys. Rev. B (Rapid Communications)).

3. Spin mode-switching at the edge of a quantum Hall system (in preparation with Udit Khanna, Ganapathy Murthy and Yuval Gefen).

4. Transport through Andreev bound states in a Weyl semi-metal dot (in preparation with Dibya Kanti Mukherjee and Arijit Kundu).

5. Driving controlled momentum space interferometry in Weyl semi-metals (in preparation with Dibya Kanti Mukherjee and Sourin Das).

6. Charge pumping as a signature of Majorana bound states in Aharanov-Bohm geometry (in preparation with Krashna Mohan Tripathi and Sourin Das).

7. Entanglement spectrum of an interacting one-dimensional Kitaev chain (in preparation with Namit Anand (visiting student)).

8. Bulk-edge correspondence and new topological phases in periodically driven silicene in the low frequency limit (with Ruchi Saxena and Arijit Kundu).

9. Learning to belong as an Indian physicist, to be published in the Review of Women's studies, Economic and Political Weekly, India.

Conference/Workshops Attended:

1. YITP (Yang Institute of Theoretical Physics), 50th anniversary symposium, Stonybrook University, U.S.A., Oct 8-10, 2016

Visits to other Institutes:

1. Visit to ETH, Zurich, Switzerland, April 20 - May 15, 2016
2. Visit to Weizmann Institute, Israel, 2-11 July, 2016
3. Visits to IISER, Kolkata and Saha Institute, Kolkata, July 27-29, 2016
4. Visit to Dept of Physics, Stonybrook University, U.S.A, October 3-11 (2016)

Invited Lectures/Seminars:

1. Weyl semi-metals- an introduction to our work, May 2, 2016, ETH, Zurich, Switzerland
2. Fingerprints of Majorana bound states in the Aharanov-Bohm geometry, May 9, 2016, ETH, Zurich, Switzerland
3. Colloquium on Dirac materials, Saha Institute, July 27, 2016, Kolkata
4. Colloquium on Dirac materials, IISER, July 28, 2016, Kolkata
5. Fingerprints of Majorana bound states in the Aharanov-Bohm geometry, IISER, July 29, 2016, Kolkata
6. Topological phases in condensed matter systems, October 10, 2016, Stonybrook, U.S.A
7. Topological phases in condensed matter systems, November 9, 2016, BHU, Varanasi

Academic recognition/Awards:

1. Elected Fellow of Indian Academy of Sciences
2. Outstanding referee award from American Physical Society

Other Activities:

1. Member, Academic council, MNNIT, Allahabad
2. Convenor, Faculty Advisory Committee, Infosys committee, HRI
3. Member, Local works committee, Housing allotment committee, Women's grievance cell/Internal Complaints committee, HRI
4. Taught QFT 1 Aug - Dec 2016 and 1/3 of the Condensed Matter physics 2 course (Jan-May 2017)

Ashoke Sen

Research Summary:

My work during April 2016 - March 2017 has been on different aspects of string theory.

1. Using our earlier construction of superstring field theory, Roji Pius and I gave a proof of Cutkosky rules in superstring field theory. I also gave a proof of reality of the superstring field theory action. Using these results I gave a proof of unitarity of superstring field theory.

2. I showed how using insights from superstring field theory one can unambiguously compute the real and imaginary parts of the one loop correction to the masses of unstable particles in superstring theory.

3. I showed how one can integrate out the heavy fields of superstring field theory to naturally arrive at a Wilsonian effective action satisfying the Batalin-Vilkovisky master equation.

4. Using superstring field theory I gave a proof of leading and subleading soft graviton theorem in superstring theory.

Publications

1. C. de Lacroix, H. Erbin, S. P. Kashyap, A. Sen and M. Verma, "Closed Superstring Field Theory and its Applications," arXiv:1703.06410 [hep-th].

2. A. Sen, "Subleading Soft Graviton Theorem for Loop Amplitudes," arXiv:1703.00024 [hep-th].

3. A. Sen, "Soft Theorems in Superstring Theory," arXiv:1702.03934 [hep-th].

4. A. Sen, "Equivalence of Two Contour Prescriptions in Superstring Perturbation Theory," JHEP **1704**, 025 (2017) doi:10.1007/JHEP04(2017)025 [arXiv:1610.00443 [hep-th]].

5. A. Sen, "Wilsonian Effective Action of Superstring Theory," JHEP **1701**, 108 (2017) doi:10.1007/JHEP01(2017)108 [arXiv:1609.00459 [hep-th]].

6. A. Sen, "Unitarity of Superstring Field Theory," JHEP **1612**, 115 (2016) doi:10.1007/JHEP12(2016)115 [arXiv:1607.08244 [hep-th]].

7. A. Sen, "One Loop Mass Renormalization of Unstable Particles in Superstring Theory," JHEP **1611**, 050 (2016) doi:10.1007/JHEP11(2016)050 [arXiv:1607.06500 [hep-th]].

8. A. Sen, "Reality of Superstring Field Theory Action," JHEP **1611**, 014 (2016) doi:10.1007/JHEP11(2016)014 [arXiv:1606.03455 [hep-th]].

9. R. Pius and A. Sen, "Cutkosky Rules for Superstring Field Theory," JHEP **1610**, 024 (2016) doi:10.1007/JHEP10(2016)024 [arXiv:1604.01783 [hep-th]].

Invited talks at Conferences / Workshops / Schools

1. Conference on String geometry and BPS state counting, IHP, Paris, April 2016
2. GGI 10th anniversary conference, Florence, May 2016
3. School on Fundamental Aspects of String Theory, Sao Paulo, May, 2016
4. VIII Workshop on String Field Theory and Related Aspects, Sao Paulo, May-June, 2016
5. Cargese Summer School, Cargese, June 2016
6. Strings 2016, Beijing, August, 2016
7. Strings and Fields 2016, Kyoto, August 2016
8. YITP 50th birthday celebration, Stony Brook, October 2016
9. SYMPOSIUM TO CELEBRATE THE 75TH BIRTHDAY OF JOHN SCHWARZ, Caltech, November 2016
10. Indian Strings Meeting, Pune, December 2016
11. CERN Winter school, February 2017

Courses given

1. Quantum field theory, January-April, 2017

Prasenjit Sen

Research Summary:

My research during the year was centered on two themes: two dimensional (2D) materials, and substrate supported atomic clusters, particularly for their application as catalysis.

We studied two materials on the first topic: phosphorene and transition metal (TM) tri-chalcogenides. Electronic, mechanical and transport of phosphorene nano-ribbons were studied. Interfaces of phosphorene with different metal surfaces, which will be important in electronic application of the former, were studied. Based on the knowledge we have about the TM tri-chalcogenides $CrSiTe_3$ and $CrGeTe_3$, we designed $CrCTe_3$ as a stable, layered anti-ferromagnetic semiconductor through computational means.

In the second topic, the on-going projects on Ag-Au, and Ag-Pt bimetallic clusters on alumina substrates as potential catalysts for CO oxidation reactions were completed.

I completed the invited review article on magnetism in atomic clusters (published in J Clust. Sc.). The invited chapter on binary TM-Si and TM-Ge clusters got published.

Publications:

1. A. Maity and P. Sen, *Density functional study of metal-phosphorene interfaces,* Int. J Mod. Phys. B **31**, 1750077, (2017).

2. A. Maity, A. Singh, P. Sen, A. Kibey, A. Akshirsagar and D. G. Kanhere, *Structural, electronic, mechanical, and transport properties of phosphorene nanoribbons: Negative differential resistance behavior,* Phys. Rev. B. **49**, 075422, (2016).

3. P. Sen, *Magnetism in simple metal and 4d transition metal clusters,* J Clust. Sc. **27**, 795 (2016) (**invited review**).

4. P. Sen, *Structure, Stability and Electron Counting Rules in Transition Metal Encapsulated Silicon and Germanium Clusters,* Chapter in Clusters: Structure, Bonding and Reactivity, Ed. M. T. Nguyen and B. Kiran, **Challenges and Advances in Computational Chemistry and Physics 23**, Series Ed. J. Leszczynski, Springer International Publishing AG 2017.

Preprints:

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

2. S. Singh and P. Sen, *Computational design of a robust two-dimensional anti-ferromagnetic semiconductor,* (submitted).

3. F. R. Negreiros, C. Yin, A. Halder, A. Singh, G. Barcaro, L. Sementa, E. C. Tyo, M. J. Pellin, S. Bartling, K-H. Meiwes-Broer, S. Seifert, P. Sen, S. Nigam, C. Majumder,

N. Fukui, H. Yasumatsu, S. Vajda, and A. Fortunelli, *CO oxidation by bimetallic Ag-Pt subnanometer supported clusters*, (submitted).

Conference/Workshops Attended:

1. *Asian Consortium on Computational Materials Science Theme Meeting on First Principles Calculations and Experiments: Role in Energy Research*, India, September, 2016.

2. *International Union of Materials Research Societies– International Conference on Electronic Materials*, Singapore, July, 2016.

Visits to other Institutes:

Invited Lectures/Seminars:

1. *Strain Engineering of Mobility and Other Properties of Phosphorene*, Asian Consortium on Computational Materials Science Theme Meeting on First Principles Calculations and Experiments: Role in Energy Research, SRM University, Chennai, September, 2016.

Other Activities:

1. Member of Editorial Board, Physica Scripta.

2. Taught *Condensed Matter Physics 1* during August-December, 2016; part of *Condensed Matter Physics 2* during Januray-February, 2017.

3. Reviewed papers for the following journals: Physical Chemistry Chemical Physics, Journal of Applied Physics, Journal of Inorganic Chem- istry, Physical Review Letters, Journal of Cluster Science, etc.

4. Evaluated two theses: one each IIT Hyderabad and Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore.

Ujjwal Sen

Research Summary:

In the previous academic year, our research has been in quantum information and computation, and its interface with many-body systems like quantum spin models, ultracold gas systems, photonic systems, and quantum biological systems. One of the topics that we have been working on is about quantum refrigerators. We show that one can construct a quantum absorption refrigerator that provides refrigeration only in the transient regime, by using three interacting qubits, each of which is also interacting with local heat-bath. The machine either does not provide cooling in the steady state, or the steady state is achieved after a long time. We propose a canonical form of qubit-bath interaction parameters that generates transient cooling without steady-state cooling, and claim that such a phenomenon is generic to small-scale quantum absorption refrigerators. We also show that it is generically possible to have fast cooling. We demonstrate our results for two separate models of thermalization, and show that a transient cooling without steady-state cooling is associated with generation of negligible, or no bipartite quantum correlations. For one of the models of thermalization, we find that the minimum achievable temperature of the refrigerated qubit can remain almost frozen, i.e., unchanged, for a significant region of the parameter space.

Another topic that we worked on was about spontaneous magnetization in the presence of disorder. We investigate equilibrium statistical properties of the quantum XY spin-1/2 model in an external magnetic field when the interaction and field parts are subjected to quenched or/and annealed disorder. The randomness present in the system are termed annealed or quenched depending on the relation between two different time scales - the time scale associated with the equilibriation of the randomness and the time of observation. Within a mean-field framework, we study the effects of disorders on spontaneous magnetization, both by perturbative and numerical techniques. Our primary interest is to understand the differences between quenched and annealed cases, and also to investigate the interplay when both of them are present in a system. We observe in particular that when interaction and field terms are respectively quenched and annealed, critical temperature for the system to magnetize in the direction parallel to the applied field does not depend on any of the disorders. Further, an annealed disordered interaction neither affects the magnetizations nor the critical temperatures. We carry out a comparative study of the different combinations of the disorders in the interaction and field terms, and point out their generic features.

Yet another topic that we worked on was about the response to defects in multi- and bipartite entanglement of isotropic quantum spin networks. Quantum networks are an integral component in performing efficient computation and communication tasks that are not accessible using classical systems. A key aspect in designing an effective and scalable quantum network is generating entanglement between its nodes, which is robust against defects in the network. We consider an isotropic quantum network of spin-1/2 particles with a finite fraction of defects, where the corresponding wave function of the network is rotationally invariant under the action of local unitaries, and we show that any reduced density matrix also remains unaltered under the local actions. By using quantum information-theoretic concepts like strong subadditivity of von Neumann entropy and approximate quantum telecloning, we prove analytically that in the presence of defects, caused by loss of a finite fraction of spins, the network sustains genuine multisite entanglement, and at the same time may exhibit finite moderate-range bipartite entanglement, in contrast to the network with no defects.

Other topics that we worked on include a resource theory of quantum coherence, detecting phase boundaries of the quantum spin-1/2 XXZ ladder via bipartite and multipartite entanglement transitions, effects of cavity-cavity interaction on the entanglement dynamics of a generalized double Jaynes-Cummings model, scale-invariant freezing of entanglement, activation of nonmonogamous multipartite quantum states, a no-go theorem to show that spookyfying quantum information is impossible, static and dynamical quantum correlations in phases of an alternating field XY model, genuine multipartite entanglement in superconducting phases of doped quantum spin ladders, etc.

Quantum correlations are an important resource in a variety of applications in quantum communication, including quantum cryptography, and in other areas of quantum information, as well as in many-body physics. Such correlations can broadly be divided into two sub-classes, viz. entanglement and information-theoretic quantum correlations. In January this year, the quantum information and computation (QIC) group at HRI, along with two other groups in Barcelona, Spain, wrote a review on quantum entanglement, to be published as a book chapter in a book published by Wiley. In March, the QIC group at HRI wrote a review on quantum discord and related topics, which was invited by a journal. Both these reviews are currently available on arXiv.org. We have also written a review on monogamy of quantum correlations during the previous academic year.

Publications:

1. Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Adiabatic freezing of long-range quantum correlations in spin chains,* Europhys. Lett. **114**, 60007 (2016).

2. Anindita Bera, Debraj Rakshit, Maciej Lewenstein, Aditi Sen(De), Ujjwal Sen, and Jan Wehr, *Disorder-induced enhancement and critical scaling of spontaneous magnetization in random-field quantum spin systems,* Phys. Rev. B **94**, 014421 (2016).

3. Utkarsh Mishra, Debraj Rakshit, R Prabhu, Aditi Sen(De), and Ujjwal Sen, *Constructive interference between disordered couplings enhances multiparty entanglement in quantum Heisenberg spin glass models,* New J. Phys. **18**, 083044 (2016).

4. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Superiority of photon subtraction to addition for entanglement in a multimode squeezed vacuum,* Physical Review A **93**, 0523213 (2016).

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

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

A **93**, 062344 (2016).

7. Asutosh Kumar, Sudipto Singha Roy, Amit Kumar Pal, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Conclusive Identification of Quantum Channels via Monogamy of Quantum Correlations,* Phys. Lett. A **80**, 3588 (2016).

8. Tamoghna Das, Sudipto Singha Roy, Shrobona Bagchi, Avijit Misra, Aditi Sen(De), and Ujjwal Sen, *Generalized geometric measure of entanglement for multiparty mixed states,* Phys. Rev. A **94**, 022336 (2016).

9. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Static and dynamical quantum correlations in phases of an alternating-field XY model,* Phys. Rev. A **94**, 042310 (2016).

10. Debasis Sadhukhan, Sudipto Singha Roy, Amit Kumar Pal, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Multipartite entanglement accumulation in quantum states: Localizable generalized geometric measure,* Phys. Rev. A **95**, 022301 (2017).

11. Asutosh Kumar, Himadri Shekhar Dhar, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Forbidden Regimes in Distribution of Bipartite Quantum Correlations due to Multiparty Entanglement,* Phys. Lett. A **381**, 1701 (2017).

Preprints:

1. Anindita Bera, Tamoghna Das, Debasis Sadhukhan, Sudipto Singha Roy, Aditi Sen(De), and Ujjwal Sen, *Quantum discord and its allies: a review,* arXiv:1703.10542.

2. Sreetama Das, Titas Chanda, Maciej Lewenstein, Anna Sanpera, Aditi Sen(De), and Ujjwal Sen, *The separability versus entanglement problem,* arXiv:1701.02187.

3. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Detecting phase boundaries of quantum spin-1/2 XXZ ladder via bipartite and multipartite entanglement transitions,* arXiv:1612.06831.

4. Mahasweta Pandit, Sreetama Das, Sudipto Singha Roy, Himadri Shekhar Dhar, and Ujjwal Sen, *Effects of cavity-cavity interaction on the entanglement dynamics of a generalized double Jaynes-Cummings model,* arXiv:1612.01165

5. Himadri Shekhar Dhar, Amit Kumar Pal, Debraj Rakshit, Aditi Sen (De), and Ujjwal Sen, *Monogamy of quantum correlations - a review,* arXiv:1610.01069.

6. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Scale-invariant freezing of entanglement,* arXiv:1610.00730.

7. Saptarshi Roy, Tamoghna Das, Asutosh Kumar, Aditi Sen(De), and Ujjwal Sen, *Activation of Nonmonogamous Multipartite Quantum States,* arXiv:1608.06914.

8. Kavan Modi, Arun Kumar Pati, Aditi Sen(De), and Ujjwal Sen, *Spookyfying Quantum Information is Impossible,* arXiv:1608.01695.

9. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Response to defects in multi- and bipartite entanglement of isotropic quantum spin networks,* arXiv:1607.05195.

10. Sreetama Das, Avijit Misra, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Necessarily transient quantum refrigerator,* arXiv:1606.06985.

11. Anindita Bera, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Spontaneous magnetization of quantum XY spin model in joint presence of quenched and annealed disorder*, arXiv:1606.01099.

12. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Genuine multipartite entanglement in superconducting phases of doped quantum spin ladders,* arXiv:1604.06683.

Conference/Workshops Attended:

1. *PRL-OSA Student Conference on Optics and Photonics*, India, September, 2016.

2. *International Conference on Quantum Foundations 2016*, India, October 2016.

3. *Young Quantum 2017*, India, February, 2017.

Visits to other Institutes:

1. Indian Institute of Science Education and Research, Bhopal, India, April, 2016.

Invited Lectures/Seminars:

1. , Colloquium, Indian Institute of Science Education and Research, Bhopal, India, April 2016.

2. *Quantum Correlations in Many-body Systems*, PRL-OSA Student Conference on Optics and Photonics (SCOP-2016), Physical Research Laboratory, Ahmedabad, India, September 2016.

3. *Resonating valence bond states: A quantum information perspective*, International Conference on Quantum Foundations (ICQF-2016), National Institute of Technology, Patna, India, October 2016.

Other Activities:

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

2. Utkarsh Mishra succesfully defended his thesis after working with me.

3. Guiding the theses of Asutosh Kumar, Sudipto Singha Roy, and Sreetama Das of HRI.

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

5. Served as an organizer of a meeting on "Young Quantum (YouQu-17)" held at HRI in February 2017.

6. Serving as the convenor of the Computer Committee, and member of Cluster Computing Committee at HRI.
7. Serving as referees in national and international journals.
8. Served/serving as members of the PhD committees of several PhD students, mainly inside HRI, but also outside.
9. Serving as member of International Advisory Board of Journal of Physics B.
10. Serving on Board of (founding) Editors of Quantum - an open source journal for quantum science.
11. Guided projects and numerical projects of several students at HRI.
12. Guiding/guided project works of several students from ouside HRI, mainly through the IAS program and VSP program.

Aditi Sen De

Research Summary:

Over the last three decades, it has been established that quantum correlations present in the system can be used as a resource to efficiently achieve certain information processing tasks which cannot be performed by states having vanishing quantum correlations. Several of these phenomena and protocols have already been realized in the laboratories by using different physical substrates. However, a main obstacle in realizing quantum information protocols is the fragility of entanglement to decoherence, which is exhibited by the rapid decay of entanglement with time in multiparty quantum systems exposed to environments. We have recently shown that with a proper choice of many-body substrate and environment, entanglement can be preserved over time. Moreover, we have found that the length of the freezing interval, for a chosen pair of nearest-neighbor spins, is independent of the length of the spin-chain, indicating a scale-invariance.

In another work, we have studied the frequency distribution of the first significant digits of the numbers in the data sets generated from a large class of measures of quantum correlations, which are either entanglement measures, or quantum discord-like measures. In particular, for Haar uniformly simulated arbitrary two-qubit states, we have found that the first-digit distribution corresponding to a collection of chosen computable quantum correlation quantifiers tend to follow the first-digit law, known as the Benford's law, when the rank of the states increases. This work has been selected as *Highlights 2016* in Europhysics Letters.

In recent years, characterization of ground and excited states in quantum many-body systems from quantum information theoretic perspectives have become a vibrant field of research. Specifically, it has been argued by studying several quantum spin models that entanglement can be a useful tool to detect quantum phase transitions in these systems. Recently, we have found that at zero temperature, the first derivative of bipartite entanglement can detect all the three phases, antiferromagnetic, paramagnetic and dimer, of an anisotropic XY chain with an alternating transverse magnetic field. In another work, we have determined the rich phase diagram of the ground states of a quantum spin-1/2 XXZ ladder by analyzing the variation of bipartite and multipartite entanglements.

In the year 2016-17, we have written four review papers on the role of quantum correlations in quantum information science. In particular, we have reviewed concepts and different methods associated with entanglement, quantum discord which is defined by quantizing concepts from classical information theory and their related topics. In another review, I have discussed communication protocols without security, both in a two-party and in a multiple-party domain.

Publications:

1. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Superiority of photon subtraction to addition for entanglement in a multimode squeezed vacuum*, Physical Review A **93**, 0523213 (2016).

2. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De),

and Ujjwal Sen, *Statistics of leading digits leads to unification of quantum correlations,* Europhys. Lett. **114**, 30004 (2016).

3. Utkarsh Mishra, Debraj Rakshit, R Prabhu, Aditi Sen(De) and Ujjwal Sen, *Constructive interference between disordered couplings enhances multiparty entanglement in quantum Heisenberg spin glass models,* New J. Phys. **18**, 083044 (2016).

4. Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De) and Ujjwal Sen, *Adiabatic freezing of long-range quantum correlations in spin chains,* Europhys. Lett. **114**, 60007 (2016).

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

6. Asutosh Kumar, Sudipto Singha Roy, Amit Kumar Pal, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Conclusive Identification of Quantum Channels via Monogamy of Quantum Correlations,* Phys. Lett. A **80**, 3588 (2016).

7. Anindita Bera, Debraj Rakshit, Maciej Lewenstein, Aditi Sen(De), Ujjwal Sen, and Jan Wehr, *Disorder-induced enhancement and critical scaling of spontaneous magnetization in random-field quantum spin systems,* Phys. Rev. B **94**, 014421 (2016).

8. Tamoghna Das, Sudipto Singha Roy, Shrobona Bagchi, Avijit Misra, Aditi Sen(De), and Ujjwal Sen, *Generalized geometric measure of entanglement for multiparty mixed states,* Phys. Rev. A **94**, 022336 (2016).

9. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Static and dynamical quantum correlations in phases of an alternating-field XY model,* Phys. Rev. A **94**, 042310 (2016).

10. Debasis Sadhukhan, Sudipto Singha Roy, Amit Kumar Pal, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Multipartite entanglement accumulation in quantum states: Localizable generalized geometric measure,* Phys. Rev. A **95**, 022301 (2017).

11. Asutosh Kumar, Himadri Shekhar Dhar, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Forbidden Regimes in Distribution of Bipartite Quantum Correlations due to Multiparty Entanglement,* Phys. Lett. A **381**, 1701 (2017).

12. Aditi Sen(De), *Quantum entanglement and its applications,* Current Science **112**, 1361 (2017).

Preprints:

1. Anindita Bera, Tamoghna Das, Debasis Sadhukhan, Sudipto Singha Roy, Aditi Sen(De), and Ujjwal Sen, *Quantum discord and its allies: a review,* arXiv:1703.10542.

2. Sreetama Das, Titas Chanda, Maciej Lewenstein, Anna Sanpera, Aditi Sen(De), and Ujjwal Sen, *The separability versus entanglement problem,* arXiv:1701.02187.

3. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Detecting phase boundaries of quantum spin-1/2 XXZ ladder via bipartite and multipartite entanglement transitions,* arXiv:1612.06831.

4. Himadri Shekhar Dhar, Amit Kumar Pal, Debraj Rakshit, Aditi Sen (De), and Ujjwal Sen, *Monogamy of quantum correlations - a review,* arXiv:1610.01069.

5. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Scale-invariant freezing of entanglement,* arXiv:1610.00730.

6. Saptarshi Roy, Tamoghna Das, Asutosh Kumar, Aditi Sen(De), and Ujjwal Sen, *Activation of Nonmonogamous Multipartite Quantum States,* arXiv:1608.06914.

7. Kavan Modi, Arun Kumar Pati, Aditi Sen(De), and Ujjwal Sen, *Spookyfying Quantum Information is Impossible,* arXiv:1608.01695.

8. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Response to defects in multi- and bipartite entanglement of isotropic quantum spin networks,* arXiv:1607.05195.

9. Sreetama Das, Avijit Misra, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Necessarily transient quantum refrigerator,* arXiv:1606.06985.

10. Anindita Bera, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Spontaneous magnetization of quantum XY spin model in joint presence of quenched and annealed disorder*, arXiv:1606.01099.

11. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Genuine multipartite entanglement in superconducting phases of doped quantum spin ladders,* arXiv:1604.06683.

Conference/Workshops Attended:

1. *PRL-OSA student chapter conference, PRL, Ahmedabad*, India, September, 2016.

2. *Young Quantum Meeting, HRI, Allahabad*, India, February, 2017.

Visits to other Institutes:

1. Indian Institute of Science Education and Research, Bhopal, India, April, 2017.

Invited Lectures/Seminars:

1. *Recent trends in Quantum Communication*, The Student Conference on Optics and Photonics (SCOP-2016), Physical Research Laboratory, Ahmedabad, September, 2016.

Other Activities:

1. Taught a one-semester course on "Quantum mechanics" during Aug-Dec 2016.

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

3. Guided projects of the following HRI graduate students:

(a) Suman Jyoti Dey “Entanglement and its applications” (Jan-May 2016).
(b) Saptarshi Roy “Quantum Communication” (Aug-Dec 2016).
(c) Stav Haldar “Basics of quantum information theory” (Jan-May 2017)

4. Guided project works of two students, Sourav Biswas from Indian Institute of Technology, Kanpur, and Pratibha Hegde, Yuvaraja’s College, Mysuru.

5. Served as a member of the Advisory committee of ”Young Quantum 2017 (YouQu-2017)” held at HRI in February 2017.

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

7. Serving as referees in national and international journals.

8. Serving as members of the PhD committees of Avijit Misra, Shrobona Bagchi, Debasis Mondol, Sudipto Singha Roy, Uttam Singh, Sreetama Das, Juhi Dutta, Dibya Kanti Mukherjee, Sarif Khan, and Nayabanta Swain.

Pratishruti Saha

Research Summary:

Project 1 - Impact of new-physics operators that give rise to rare top decays on single top production at the LHC : The LHC is a top factory and provides an opportunity for detailed studies of the properties of the top quark. This includes rare top decays. In some earlier works we have studied the decay $t \to b\bar{b}c$ using effective operators to capture the effects of physics beyond the Standard Model in such decays. It is obvious that such operators would also contribute to single top production. The contribution is somewhat subdued as it requires the presence of heavy quarks in the initial state. Nonetheless, it is expected that the effects would be substantial enough to be observable at the LHC. While top quark decay is a useful probe when the energy scale of the new physics lies in the vicinity of the top quark mass, i.e. a few hundred GeVs, for new physics that resides at a higher energy scale, the effect on top quark decay is too small to be discernible. Single top production, on the other hand, would be sensitive to new physics effects at energy scales of $\mathcal{O}$(TeV) or even $\mathcal{O}$(10 TeV). We use single top production in the s−channel as well as the t−channel to constrain the parameter space. We also study the net top polarization as a means to distinguish between contributions from operators with different Lorentz structures and fermion chiralities.

Project 2 - Non-standard coupling of the Higgs boson with bottom quarks : The 125 GeV scalar discovered at the LHC in 2012 is by-and-large accepted to be the scalar boson associated with the Higgs mechanism. However, the Standard Model only incorporates the minimal version of this mechanism. Theoretically, several variants of this mechanism are equally likely to exist. Experiments have to determine which of these is actually realised in nature. One of the ways of doing this is to study the couplings of the Higgs boson to other Standard Model particles. In particular, the coupling of the Higgs boson to bottom quarks is rather difficult to study at the LHC owing to the large QCD background. We propose a study of this coupling at a future e^+e^- collider. We estimate the significance with which the existence of non-standard couplings can be established. We also attempt to identify observables that can distinguish between scalar and pseudoscalar $hb\bar{b}$ couplings.

Visits to other Institutes:

1. IISER Kolkata, Mohanpur, West Bengal, India, April, 2016 - Presented seminar titled *"Rare Top Decays as a probe for Physics Beyond the Standard Model"*.

2. University of Delhi, Delhi, India, July, 2016 - Conducted a short workshop (6 hours spread over 3 days) on ROOT Data Analysis Framework.

Other Activities:

1. Taught approximately half of the "Research Methodology and Numerical Methods" course during August-December, 2016. The topics covered were

    - Introduction to programming languages : C++ including basics of object-oriented programming

- Generation and use of random numbers
- Sorting and searching
- Integration using Monte Carlo techniques
- Optimisation, extrema of many variable functions

As an add-on, I introduced the ROOT Data Analysis Framework developed at CERN (https://root.cern.ch). While ROOT has a broad scope and can be used for a wide variety of applications related to data analysis and representation, in this course it was introduced mainly as a tool for minimization and curve fitting problems (MINUIT routines which were widely used for several decades for such problems are now accessible via ROOT) and for Monte Carlo simulations/pseudo-experiments which require random numbers with particular profiles.

Khorsed Alam

Research Summary:

I have done two projects. One is learning basics of Density Functional Theory, and doing some elementary band structure and density of states calculations using VASP.

Another project was to study magnetism in a triangular lattice using Hubbard Model mean field solution.

Visits to other Institutes:

1. NISER, Bhubaneswar, India, May-July, 2016.

Other Activities:

1. Audited the course, Condensed Matter Physics-1, August-Novemver, 2016.
2. Audited the course, Condensed Matter Physics-2, January-April, 2017

Aditya Banerjee

Research Summary:

In this academic year, I have mainly worked on two topics. First, I worked on problems of effects of interaction and/or disorder in certain classes of topological Weyl semimetals. Specifically, i looked at the effects of long range interactions as well as disorder in the so-called triple-Weyl semimetals. Using renormalization group calculations, I calculated the fixed point behaviour of this system and the consequent signatures in observable quantities such as the conductivities and specific heat. Calculations of some of these quantities were also supplemented by calculations done within the framework of Boltzmann transport theory. An article on this has been submitted to the European Physical Journal-B. Additionally, I also looked at effects of disorder on the nodal-loop semimetals.

Second, in collaboration with Prof. Subhro Bhattacharjee at ICTS-TIFR (Bangalore), I have worked on the problem of giving a unified fermionic theory for the quantum phase transitions involving spiral order, valence bond solids and Z_2 spin liquids. Phase transitions involving these phases in two space dimensions are well understood in the bosonic framework and has been the central arena for the emergence of deconfined quantum criticality. However, a fermionic description has only been in patches and has excluded the Z_2 spin liquid phase. We have attempted to confront this issue from looking at the various possible projective symmetry invariant Dirac masses and constructing, first, a non-linear sigma model description of this problem and try to look at the phase transitions involving these three phases from our perspective. This work will eventually also include examining possible boson-fermion dualities coming from describing the same set of phases and their transitions from both the bosonic and fermionic approach. This work is currently on-going and a preprint is expected soon.

Preprints:

1. Aditya Banerjee, *Effects of Coulomb interactions and disorder on triple-Weyl semimetals*, (submitted to EPJB)

Conference/Workshops Attended:

1. *School on current frontiers in quantum condensed matter*, ICTS Bangalore, India, June, 2016.

2. *Jerusalem winter school in theoretical physics - New Horizons in Quantum Matter*, Jerusalem, Israel, January, 2017.

Jyotiranjan Beuria

Research Summary:

During this academic year (April 2016 to March 2017), I along with my collaborators, have studied the vacuum structure of the Next-to-Minimal Supersymmetric Model (NMSSM) in the context of three neutral fields getting vacuum expectation values and charged and coloured fields getting vacuum expectation values. We have also studied the collider phenomenology of Minimal Universal Extra Dimension (MUED).

Publications:

1. Jyotiranjan Beuria, Utpal Chattopadhyay, AseshKrishna Datta, Abhishek Dey, *Exploring viable vacua of the Z_3 symmetric NMSSM* JHEP **024**, 1704, (2017)

2. Jyotiranjan Beuria, Arindam Chatterjee, AseshKrishna Datta, *Sbottoms of Natural NMSSM at the LHC,* JHEP **004**, 1608, (2016)

Preprints:

1. Jyotiranjan Beuria, AseshKrishna Datta, Dipsikha Debnath, Konstantin T. Matchev *LHC Collider Phenomenology of Minimal Universal Extra Dimensions,* arXiv:1702.00413, HRI-P-17-02-01, RECAPP-HRI-2017-002

Conference/Workshops Attended:

1. *SUSY-DM*, Indo-French Kick-off Meeting, IISC, Bangalore, May 2016

2. *XXII DAE-BRNS High Energy Physics Symposium 2016*, Delhi University, December 2016

3. *Looking into BSM Physics*, IISC, Bangalore, December 2016

Visits to other Institutes:

1. *TIFR*, Mumbai, May 2016

Ritabrata Bhattacharya

Research Summary:

In the Academic Year 2016-2017 I have been working on issues related to the generalization of the SYK model to 2D. A recent paper by Verlinde produced a 2D action for Majorana fermions containing a kinetic term which is topological and as a consequence the fermions are dimension less allowing us to write a Hamiltonian in 2D which is SYK like. Our primary goal at present is to work the 4 point OTOC to check whether the lyapunov exponent satisfies the chaos bound following the work of Maldacena and Stanford.

Conference/Workshops Attended:

1. *Indian Strings Meet, India, December, 2016.*
2. *SERC school, India, January, 2017*

Visits to other Institutes:

1. Saha Institute of Nuclear Physics, Kolkata, India, April, 2017.

Sauri Bhattacharyya

Research Summary:

In this academic year, I tried to extend the formulation of a quantum fluctuation theory on top of the Static Path Approximation (SPA) method, already implemented for electron-phonon systems, to the attractive and repulsive Hubbard problems. The main intent is to compute the low-energy collective mode spectrum at finite temperature and density in both the situations, connecting up the results to the BCS-BEC problem in the attractive case, and to the Mott transition in the other one. Ultimately, we're also trying to understand the role played by these modes in the bulk transport of the system in the attractive case.

We have some results in the attractive Hubbard problem regarding the temperature dependence of collective mode spectra on SPA backgrounds and also the effect of disorder on those across the Superconductor-Insulator transition (SIT) at intermediate coupling, relevant for experiments. The repulsive problem on the square and triangular lattice are being studied and preliminary results for spin wave spectra are already at hand. The previous results on Holstein phonons across the polaronic transition are being written up.

Preprints:

1. Sauri Bhattacharyya, Saurabh Pradhan and Pinaki Majumdar *Signatures of the polaronic crossover in phonon spectra* (in preparation)

Conference/Workshops Attended:

1. *HRI Discussion Meeting on Nonequilibrium Quantum Many Body Physics*, India, November, 2016.

Subhroneel Chakrabarti

Research Summary:

During the academic year 2016-2017, I continued my work in using pure spinor techniques to compute 2 loop mass renormalization of first massive state in $SO(32)$ heterotic string theory. This is a work being done in collaboration with Prof.Ashoke Sen and fellow graduate students Sitender Pratap Kashyap and Mritunjay Kumar Verma. While doing this we found a covariant way of systematically obtaining the θ expansion of various superfield that apears in unintegrated massive vertex. This was previously unknown in literature. We have also made huge progress in constructing the integrated vertex(so far unknown in literature) which is essential to compute mass renormalization. Both of this is expected to be completed very soon.

In addition I have also worked in two seperate problems. First is to obtain subleading soft graviton theorem for any number of external soft gravitons in superstring field theory. This is also being done in collaboration with Prof.Ashoke Sen and fellow graduate students Sitender Pratap Kashyap and Mritunjay Kumar Verma. We have made progress into this. Secondly, I have worked in SYK model with Prof.Dileep Jatkar, Dr.Arnab Kundu (SINP) and fellow graduate student Ritabrata Bhattacharya. We have looked into the effect of introducing a chemical potential in SYK model. We have also looked into possible chaotic behaviour of a 2 dimensional generalization of SYK model by studying their 4-point out-of-time-ordered correlation functions. Both of these are in rapid progress.

Preprints:

1. Subhroneel Chakrabarti,Sitender Pratap Kashyap and Mritunjay Kumar Verma, *Theta Expansion of First Massive Vertex Operator in Pure Spinor* (in preparation).

Conference/Workshops Attended:

1. *Indian Strings Meeting*, India, December, 2016.

Other Activities:

1. Tutored for the course Quantum Field Theory I, August-December,2016.

Titas Chanda

Research Summary:

During the last academic year, I have been working on various aspects of quantum information science, mainly on the interface between quantum information science and many-body physics.

We have investigated the static and dynamical patterns of entanglement in an anisotropic XY model with an alternating transverse magnetic field, which is equivalent to a two-component one-dimensional Fermi gas on a lattice, a system realizable with current technology. Apart from the antiferromagnetic and paramagnetic phases, the model possesses a dimer phase which is not present in the transverse XY model. At zero temperature, we have found that the first derivative of bipartite entanglement can detect all the three phases. We have analytically shown that the model has a "factorization line" on the plane of system parameters, in which the zero temperature state is separable. Along with investigating the effect of temperature on entanglement in a phase plane, we have also reported a non-monotonic behavior of entanglement with respect to temperature in the anti-ferromagnetic and paramagnetic phases, which is surprisingly absent in the dimer phase. Since the time dynamics of entanglement in a realizable physical system plays an important role in quantum information processing tasks, the evolutions of entanglement at small as well as large time are examined. Consideration of large time behavior of entanglement helps us to prove that in this model, entanglement is always ergodic. We have observed that other quantum correlation measures can qualitatively show similar features in zero and finite temperatures. However, unlike nearest-neighbor entanglement, the nearest-neighbor information theoretic measures can be both ergodic as well as non-ergodic, depending on the system parameters.

We have shown that bipartite entanglement can be frozen over time with a proper choice of the many-body substrate, which is in contact with one, or more than one environments via a repetitive interaction. Choosing the one-dimensional anisotropic XY model in transverse uniform or alternating fields as the system, we have shown, in systems of moderate size, that the numerically obtained freezing, or near-freezing of entanglement occurs in all three phases, namely, the dimer, the antiferromagnetic, and the paramagnetic phases of the model. We have also shown that in the dimer and the paramagnetic phases, the length of the freezing interval, for a chosen pair of nearest-neighbor spins, is independent of the length of the spin-chain, indicating a scale-invariance. This allows us to propose a relation between the length of the freezing interval and the distance of the chosen pair of spins with the environment. Since the phenomenon also occurs in the one-dimensional XXZ model in an external field as well as in the $J_1 - J_2$ spin chain under the same decoherence scheme, we argue that this feature is potentially generic to the low-dimensional quantum spin models.

We also have introduced a review of the problem of finding out whether a quantum state of two or more parties is entangled or separable. After a formal definition of entangled states, we have presented a few criteria for identifying entangled states and introduce some entanglement measures. We have also provided a classification of entangled states with respect to their usefulness in quantum dense coding, and have presented some aspects of multipartite entanglement.

Publications:

1. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Static and dynamical quantum correlations in phases of an alternating field XY model,* Physical Review A **94**, 042310, (2016).

Preprints:

1. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Scale-invariant freezing of entanglement,* arXiv:1610.00730.

2. Sreetama Das, Titas Chanda, Maciej Lewenstein, Anna Sanpera, Aditi Sen(De), and Ujjwal Sen, *The separability versus entanglement problem*, Book Chapter, arXiv:1701.02187.

Conference/Workshops Attended:

1. *International Conference on Quantum Foundations 2016*, India, October, 2016.

2. *Young Quantum - 2017*, India, February, 2017.

Other Activities:

1. Presented a poster titled "Frozen quantum correlations" at ICQF-2016 held at NIT Patna, October, 2016.

Kasinath Das

Research Summary:

In the last academic year I was working on possible signatures of beyond Standard Model particles in different gauge extensions of Standard Model at LHC. In one of our work I with my collaborators had tried to accomodate the excess observed around 750 GeV diphoton invariant mass that had been observed by ATLAS and CMS at LHC, in an $U(1)$ extension of Standard Model which is embodied in an E_6 model. After including collider data of higher luminosities, the excess did not remain. With the same E_6 model we have studied one of the possible new signatures of vector like downtype quarks at LHC.

Publications:

1. Kasinath Das and Santosh Kumar Rai, *750 GeV diphoton excess in a $U(1)$ hidden symmetry model*, Phys. Rev. D **93**, 095007, (2016).

Preprints:

1. Kasinath Das, Tianjun Li, S. Nandi, Santosh Kumar Rai, *A new proposal for diphoton resonance from E_6 motivated extra $U(1)$*, hep-ph/arXiv:1607.00810.

2. Kasinath Das, Tianjun Li, S. Nandi, Santosh Kumar Rai, *New signals for vectorlike downtype quark in $U(1)$ of E_6*, in preparation.

Conference/Workshops Attended:

1. *Indo-French LIA THEP and CEFIPRA INFRE-HEPNET Kick Off Meeting*, IISC Banglore, India, 2nd-5th May 2016.

2. *CTEQ-MCnet School*, DESY, Hamburg, Germany, 6th-16th July 2016.

3. *XXII DAE-BRNS High Energy Physics Symposium*, University Of Delhi, India, 12th-16th Dec. 2016.

Visits to other Institutes:

1. IACS, Kolkata, India, 18th-28th March 2017.

Sreetama Das

Research Summary:

In the last academic year, I have worked on quantum thermodynamics under the supervision of Prof. Ujjwal Sen. Quantum thermodynamics is a branch of physics in which the effect of quantum mechanics on thermodynamical laws and thermodynamical properties is observed. Previously, thermodynamics was mostly applied to macroscopic systems. With the developement of quantum thermodynamics, thermodynamics has been extended into the regime where there are mesoscopic or even a small number of systems. I have, in particular, been working on quantum refrigerators, which is a quantum thermal machine composed of multiple qubits and their respective baths, which is used to cool one part of the machine.

Also, I have studied quantum entanglement in many-body systems such as a chain of quantum spin-1/2 particles.

Preprints:

1. C. Mukhopadhyay, S. Das, S. Bhattacharya, A. Sen. De and U. Sen "*Qunatum coherence in superposition with non-distinguishable pointers*", arXiv:1705.04343 [quant-ph].

2. S. Das, T. Chanda, M. Lewenstein, A. Sanpera, A. Sen. De and U. Sen "*The separability versus entanglement problem*", arXiv:1701.02187 [quant-ph].

3. M. Pandit, S. Das, S.S. Roy, H.S. Dhar, A. Sen. De and U. Sen "*Effects of cavity-cavity interaction on the entanglement dynamics of a generalized double Jaynes-Cummings model*", arXiv:1612.01165 [quant-ph].

4. S. Das, A. Misra, A.K. Pal, A. Sen. De and U. Sen "*Necessarily transient quantum refrigerator*", arXiv:1606.06985 [quant-ph].

Conference/Workshops Attended:

1. *ICQF16*, NIT, Patna, 17^{th} October to 21^{st} October, 2016.

2. *Young Qunatum* , HRI, Allahabad, 27^{th} February to 1^{st} March, 2017.

Satadal Datta

Research Summary:

We have studied Newtonian spherically symmetric transonic accretion by in- cluding the self gravity of the accreting matter, while considering the growth of the accretor itself to be negligibly small. A novel iterative method is in- troduced to accomplish that task. It is demonstrated that the inclusion of the mass of the fluid changes the critical properties of the flow as well as the topological phase portraits of the stationary integral solution. The changes are small in the framework of this methodology. It is shown that to get large changes one has to develop a new method. Weve done another work on acoustic analogue of gravity. For accretion onto astrophysical black holes, we demonstrate that linear perturbation of Bernoullis constant defined for inviscid ir-rotational adiabatic flow of perfect ideal fluid gives rise to phenomena of analogue gravity. The formulation of our work is done in Newtonian framework and also within the General relativistic frame work, i.e; considering a static space time back ground, as well. The resulting structure of the analogue acoustic metric is similar to the acoustic metric found in perturbing velocity potential and mass accretion rate. In static and spherically symmetric spacetime, we solve the Einstein Maxwell equations. The effective gravitational potential and the electric field for charged anisotropic fluid are defined in terms of two free parameters. For such configuration, the mass of the star as a function of stellar radius is found in terms of two aforementioned parameters, subjected to certain stability criteria. For various values of these two parameters one finds that such mass radius relationship can model stellar objects located at various regions of Hertzsprung-Russel diagram.

Publications:

1. Satadal Datta, *Bondi flow revisited,* Astrophys Space Sci (2016) **361**, 260, (2016).
2. Satadal Datta, Md Arif Shaikh and Tapas K Das, *Acoustic Geometry obtained through the perturbation of the Bernoullis constant,* arXiv:1612.07954 (2016)
3. Safiqul Islam, Satadal Datta and Tapas K Das, *A parametric model to study the mass radius relationship of stars,* arXiv:1702.05171 (2017)

Conference/Workshops Attended:

1. *1. XXXV Meeting of Astronomical Society of India*, India, March, 2017.

Juhi Dutta

Research Summary:

We have worked on compressed supersymmetric spectra for extensions of the minimal supersymmetric standard model (MSSM). A light gravitino (in the keV range) in the spectrum, as the lightest supersymmetric particle(LSP) lead to interesting collider signatures. Strongly interacting particles decay to the lightest neutralino (in our case, a bino-like neutralino which is the next to lightest SUSY particle (NLSP)) which further decay to the gravitino LSP along with a hard photon or a Z boson. From our previous work on compression in the MSSM sector, we concluded that for effective compression in the spectrum fulfilling all collider and dark matter constraints, heavy sparticles in the TeV mass range are required. Such a heavy spectrum will produce one or more hard photons from the decays of the NLSP to the LSP along with large missing transverse momentum carried away by the gravitino. Since such hard photons are extremely are rare from the Standard Model backgrounds, these signals are a relatively clean channel to look for at colliders. We explore the discovery prospects of the signals for both compressed and uncompressed spectra in the photon + multi-jet + missing transverse energy signals. We find the Run 2 data at LHC can exclude compressed spectra upto nearly 2.5 TeV or more even before the high luminosity run of LHC. Since hard photons are expected for both uncompressed and compressed scenarios with such a light gravitino LSP, we have also explored different kinematic variables to distinguish a compressed and uncompressed spectra with similar signal event rates at LHC.

Neutrino oscillation experiments have established affirmatively non-zero masses for neutrinos. However neither the Standard Model nor its minimal supersymmetric (MSSM) version accounts for the same. We have been studying extensions of of the phenomenological MSSM model with a right handed Majorana neutrino superfield in the context of natural supersymmetry. Such an extended model explains light neutrino masses and involves the right sneutrino as the LSP and dark matter candidate. We have focussed on the electroweak sector. In presence of mixing between the left and right sneutrino, a large number of leptonic decay channels open up, thereby giving rise to multiple leptons with large missing transverse energy carried away by the LSP which are interesting to study at colliders. We study such signals at 13 TeV LHC for spectra fulfilling all collider constraints (such as the lightest CP-even Higgs mass constraints) as well as dark matter relic density and direct detection constraints.

Preprints:

1. Juhi Dutta, Partha Konar, Subhadeep Mondal, Biswarup Mukhopadhyaya, Santosh Kumar Rai, *Search for a compressed spectrum with a light Gravitino,* arXiv 1704.04617 (2017).

2. Arindam Chatterjee, Juhi Dutta and Santosh Kumar Rai, *Natural SUSY and Right Sneutrino Dark Matter,* (in preparation)

Conference/Workshops Attended:

1. *Indo-French LIA THEP and CEFIPRA INFRE-HEPNET Kick Off Meeting*, IISc Bengaluru, India, May, 2016.

2. *750 GeV Excess @ LHC Under Scrutiny*, ICTS Bengaluru, India, May, 2016.

3. *XXXI SERC Main School in Theoretical High Energy Physics*, University of Kalyani, West Bengal, India, January, 2017.

Visits to other Institutes:

1. Indian Statistical Institute, Kolkata, India, October, 2016.

Other Activities:

1. Teaching Assistant in Classical Mechanics Course, August-December, 2016.

Siddharth Dwivedi

Research Summary:

During the academic year 2016-17, I along with my collaborators, have been working on the study of non-standard Higgs interactions within the framework of Effective Field Theory in a model independent approach. Such effective interaction terms arising out of gauge invariant dimension six operators serve as a potential source of new physics. The interaction in context is the h-b-$\bar{b}$-γ anomalous vertex, involving the coupling of the Higgs boson (h) to the $b, \bar{b}$ quark- antiquark pair and a photon (γ).

The phenomenology of such anomalous couplings (absent in the Standard Model (SM)) has been studied by considering some detectable final states where these couplings play a role. We have considered the bounds coming from the existing collider and other low energy experimental data in order to derive constraints on the potential new physics couplings and predict possible collider signals in the context of 14 TeV LHC and and a future e^+e^- machine. We conclude that the anomalous h-b-$\bar{b}$-γ coupling can be probed at the LHC at 14 TeV center of mass energy at the 3σ level with an integrated luminosity of $\sim 2000\ \text{fb}^{-1}$, which an e^+e^- collider can probe at the 3σ level with $\sim 12(7)\ \text{fb}^{-1}$ at the center of mass energy $(\sqrt{s}) = 250(500)$ GeV. It is also found that anomalous h-b-$\bar{b}$ interactions, subject to the existing LHC constraints, can not compete with the rates driven by h-b-$\bar{b}$-γ effective interactions.

Preprints:

1. Siddharth Dwivedi, Subhadeep Mondal, Biswarup Mukhopadhyaya, *Exploring anomalous $hb\bar{b}$ and $hb\bar{b}\gamma$ couplings in the context of the LHC and an e^+e^- collider*, arXiv:1702.06003.

Conference/Workshops Attended:

1. *XXII DAE-BRNS High Energy Physics Symposium*, India, December, 2016.
2. *Indo-French LIA THEP and CEFIPRA INFRE-HEPNET Kick-Off Meeting*, India, May, 2016.

Visits to other Institutes:

1. Laboratoire d'Annecy-le-Vieux de Physique Thorique (LAPTh), Annecy, France, November, 2016 .

Avirup Ghosh

Research Summary:

In the academic year 2016-17 I have studied a set of simple BSM models which propose a viable non-thermal Dark Matter candidate. Such models have very interesting collider signature due to the non-thermal nature of the Dark Matter candidate. LHC phenomenology of such signals are being studied by me as a part of my PhD thesis work.

Conference/Workshops Attended:

1. *School cum workshop on Collider Physics : Events,Analysis and QCD*, India, March, 2017.

Aritra Gupta

Research Summary:

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

In the second work, we have studied a non-thermal (fermionic) dark matter scenario in the light of a new type of $\mathrm{U(1)_{B-L}}$ model. The $\mathrm{U(1)_{B-L}}$ model is interesting, since, besides being anomaly free, it can give rise to neutrino mass by Type II see-saw mechanism. Moreover, as we will show, it can accommodate a non-thermal fermionic dark matter as well. Starting from the collision terms, we have calculated the momentum distribution function for the dark matter by solving a coupled system of Boltzmann equations. We then used it to calculate the final relic abundance, as well as other relevant physical quantities. We have also compared our result with that obtained from solving the usual Boltzmann (or rate) equations directly in terms of comoving number density, Y. Our findings suggest that the latter approximation is valid only in cases where the system under study is close to equilibrium, and hence should be used with caution.

In the third work, we study the implications of the premise that any new, relativistic, highly energetic neutral particle that interacts with quarks and gluons would create cascade-like events in the IceCube (IC) detector. Such events would be observationally indistinguishable from neutral current deep-inelastic scattering events due to neutrinos. Consequently, one reason for deviations, breaks or excesses in the expected astrophysical power-law neutrino spectrum could be the flux of such a particle. Motivated by features in the recent 1347-day IceCube high energy starting event data (HESE), we focus on particular boosted dark matter (χ) related realizations of this premise. Here, χ is assumed to be much lighter than, and the result of, the slow decay of a massive scalar (ϕ) which constitutes a major fraction of the Universe's dark matter. We show that this hypothesis, coupled with a standard power-law astrophysical neutrino flux is capable of providing very good fits to the present data, along with a possible explanation of other features in the HESE sample. These features include a) the paucity of events beyond 2 PeV b) a spectral feature resembling a dip or a spectral change in the 400 TeV–1 PeV region and c) an excess in the 50100 TeV region. We consider two different boosted DM scenarios, and determine the allowed mass ranges and couplings for four different types of mediators (scalar, pseudoscalar, vector and axial-vector) which could connect the standard and dark sectors. We consider constraints from gamma-ray observations and collider searches. We find that the gamma-ray observations provide the most restrictive constraints, disfavouring the 1 allowed parameter space from IC fits, while still being consistent with the 3 allowed region. We also test our proposal and its implications against IC's recent six-year through-going muon track data.

In the fourth work, we explore the intermediate dark matter mass regime of the inert Higgs doublet model (IHDM) by extending the model with three copies of right handed singlet neutrinos. The in built discrete Z2 symmetry of the model allows these right handed neutrinos to couple to the usual lepton doublets through the inert Higgs doublet allowing the possibility of radiative neutrino mass in the scotogenic fashion. Apart from generating non-zero neutrino mass, such an extension can also revive the intermediate dark matter mass regime, between W boson mass to a few hundred GeV's where pure IHDM can not give rise to correct dark matter relic abundance. The late decay of the lightest right handed neutrino to dark matter makes it possible for the usual thermally under-abundant dark matter in this intermediate mass regime to satisfy the correct relic abundance limit. The revival of this wide intermediate mass range can not only have relevance for direct search experiments but also for neutrino experiments as the long lifetime of the lightest right handed neutrino also results in almost vanishing lightest neutrino mass.

Publications:

1. Anirban Biswas, Aritra Gupta, *Freeze-in Production of Sterile Neutrino Dark Matter in U(1)$_{\mathrm{B-L}}$ Model*, JCAP 1609 no.09, 044, (2016).

2. Atri Bhattacharya, Raj Gandhi, Aritra Gupta, Satyanarayan Mukhopadhyay, *Boosted Dark Matter and its implications for the features in IceCube HESE data*, JCAP05 002 (2017).

3. Anirban Biswas, Aritra Gupta, *Calculation of Momentum Distribution Function of a Non-thermal Fermionic Dark Matter,* JCAP03 033 (2017).

Preprints:

1. Debasish Borah, Aritra Gupta, *A New Viable Region of Inert Higgs Doublet Dark Matter Model with Scotogenic Extension*, 1706.05034.

Conference/Workshops Attended:

1. *DAE conference 2016*, Delhi University, Delhi, INDIA, December 2016.

Visits to other Institutes:

1. *IIT Guwahati*, Guwahati, Assam, INDIA, January 2017.

2. *Tata Institute of Fundamental Research*, Mumbai, INDIA, February 2017.

Invited Lectures/Seminars:

1. *Calculation of Momentum Distribution Function of a Non-thermal Fermionic Dark Matter*, IIT Guwahati, Guwahati, January, 2017.
2. *Boosted Dark Matter and its implications for the features in IceCube HESE data*, TIFR, Mumbai, February, 2017.

Arpan Kar

Research Summary:

During the academic year 2016-2017 our research work was focoused on the study of astrophysical constraints on MSSM dark matter. We have tried to see how minimal supersymmetric extension of standard model can explain the astrophysical signal coming from various galaxies and galaxy-clusters in the multifrequency range from synchroton radiation to γ ray radiation. With the help of these we have tried to probe the supersymmetric parameter space allowed to produce these signal.

Conference/Workshops Attended:

1. *SERC MAIN SCHOOL*, India, January, 2017.
2. *SANGAM*, India, February, 2016.

Visits to other Institutes:

1. NCRA, Pune, India, December, 2016.
2. NCRA, Pune, India, April, 2017.

Sitender Pratap Kashyap

Research Summary:

We worked on construction of integrated vertex operator for massive strings at first excited level. The work is still in progress, but, along the way we made some progress in better understanding of the same vertex operator in the unintegrated form.

We also wrote a review on *closed superstring field theories*. We reviewed the systematic procedure to determine the shift in the vacuum expectation values of field due to quantum corrections, determining the renormalized masses and compute the S-matrix of the theory around this shifted vacuum. This helps us get rid of the infra-red divergences from string theories when the non-compact dimensions is greater than four.

Preprints:

1. Corinne de Lacroix , Harold Erbin , Sitender Pratap Kashyap ,Ashoke Sen, Mritunjay Verma, *Closed Superstring Field Theory and its Applications,* HRI/ST/1701.

Conference/Workshops Attended:

1. *Indian Strings Meeting*, India, December, 2016.

Visits to other Institutes:

1. Perimeter institute, Ontario, Canada, July-August, 2016

Sarif Khan

Research Summary:

The success of Standard Model (SM) in explaining all the observed phenomenon implies that it is a cocreate theory of nature. Recent discovery of the Higgs boson at CERN add another success in its crown. Despite its many success it has some limitations in addressing all the observed phenomenon of nature. The limitations are,

1. we know that visible and invisible matter contain only 4% and 24% of the total energy budget of the universe. The latter invisible matter is electromagnetically blind hence it is called dark matter (DM). Remaining 72% is called the dark energy. SM does not contain any candidate for the DM.

2. Neutrino oscillation among the flavors implies that neutrinos have mass. In SM there is no right handed (RH) counterpart of the left handed (LH) neutrinos. Hence, we can not give it mass in the way we give mass to quarks. Therefore, SM is unable to explain the tiny neutrino mass and we need to answear this.

3. There is a small asymmetry of matter over anti-matter ($Y_B \sim 8.67 \times 10^{-10}$) in the universe. SM can not explain this asymmtery and still unknown to us.

4. If one calculate muon $(g-2)$ by taking all the contributions of SM and the experimentally observed value of it disagree ($\Delta a_\mu \sim 29.0 \times 10^{-10}$). Hence we need to add some extra contribution to agree with experiment.

there are many more unsolved questions which can not be explained just by considering SM.

It is clear from the above discussion that we need to extend the SM to explain all these unexplained things. One of the way to tackel these problems is to expand the SM gauge group $(SU(3)_c \times SU(2)_L \times U(1)_Y)$. I have considered $U(1)_{B-L}$ and $U(1)_{L_\mu - L_\tau}$ extension of SM separately in addressing the above unsolved problems. In explaining DM I have considered SM singlet scalar and it can successfully explain the observed DM relic density by WMAP and Planck. I have also studied two different DM production mechanism freeze out and frreze in. In the previous mechanism it always stays in thermal equilibrium with the thermal soup and for the latter mechanism it never attains thermal equilibrium with the thermal soup. In explaining the neutrino mass, I have added three RH neutrinos to the particle list of SM and by Type I seesaw mechanism, tiny nautrino masses have been generated. All the extension are gauged hence a extra gauge boson are there in the particle list. For the $U(1)_{L_\mu - L_\tau}$ extension of SM we have explained muon $(g-2)$ by considering extra one loop diagram mediated by this extra gauge boson. In explaining the matter anti-matter asymmetry of the universe, we have generated lepton asymmetry from the RH neutrinos decay and then converted this lepton asymmetry to baryon asymmetry through the sphaleron process.

Publications:

1. A. Biswas, S. Choubey and S. Khan, "*Galactic gamma ray excess and dark matter phenomenology in a $U(1)_{B-L}$ model*", JHEP **1608**, 114 (2016), doi:10.1007/JHEP08(2016)114, [arXiv:1604.06566 [hep-ph]].

2. A. Biswas, S. Choubey and S. Khan, "*Neutrino Mass, Dark Matter and Anomalous Magnetic Moment of Muon in a* $U(1)_{L_\mu - L_\tau}$ *Model*", JHEP **1609**, 147 (2016), doi:10.1007/JHEP09(2016)147, [arXiv:1608.04194 [hep-ph]].

3. A. Biswas, S. Choubey and S. Khan, "*FIMP and Muon* $(g-2)$ *in a* $U(1)_{L_\mu - L_\tau}$ *Model*", JHEP **1702**, 123 (2017), doi:10.1007/JHEP02(2017)123, [arXiv:1612.03067 [hep-ph]].

Preprints:

1. A. Biswas, S. Choubey and S. Khan, "*Neutrino Mass, Leptogenesis and FIMP Dark Matter in a* $\mathrm{U(1)_{B-L}}$ *Model*", arXiv:1704.00819 [hep-ph].

Conference/Workshops Attended:

1. *Invisible 16 School, SISSA, Trieste*, Italy, September 5^{th} to 9^{th}, 2016.

2. *Invisible 16 Workshop, INFN Padova*, Italy, September 12^{th} to 16^{th}, 2016.

3. *XXII DAE-BRNS HIGH ENERGY PHYSICS SYMPOSIUM 2016, University of Delhi*, India, December 12^{th} to 16^{th}, 2016

Abhass Kumar

Research Summary:

During the academic year 2016-2017, I have continued my study towards combining inflation and dark matter into one framework. I have used the inert doublet model non-minimally coupled to gravity. The inert doublet acts as the inflaton in the early universe. To use the model to calculate inflationary parameters, we need to make a conformal transformation to a frame called the Einstein frame. This is different from the usual physical frame, also called the Jordan frame, in that there are no explicit couplings of the field to gravity. All references to gravity come from field redefinitions. This frame thus allows us to handle the problem as a normal field theory lagrangian. In this frame, with the absence of any other field apart from the transformed inert doublet fields, the potential takes a form which belongs to a general class of Starobinsky potentials. The potential obtained is a slowly rolling one at fields much higher than the reduced Planck mass and causes inflation with predicted values of parameters matching very well with experiments. At the end of inflation, the universe needs to be reheated as inflation renders it almost empty. This is achieved by the decay of the inflaton into gauge bosons and the higgs boson. These particles produced are non-relativistic with very high effective masses and further decay or annihilate into relativisitc fermions to finally reheat the universe. After reheating, the inflaton field falls off to values low enough that the conformal transformation effectively becomes 1 and the Einstein and Jordan frames become equivalent. At this point the inert doublet is in thermal equilibrium with the rest of the plasma and later freezes out to become a heavy cold dark matter candidate.

Preprints:

1. Sandhya Choubey and Abhass Kumar, *Inflation and dark matter in the inert-doublet model,* (in preparation)

Conference/Workshops Attended:

1. 22^{nd} *DAE-BRNS High Energy Physics Symposium*, India, December, 2016.

Visits to other Institutes:

1. Center for Theoretical Physics, Jamia Millia Islamia (Central University), New Delhi, India, December, 2016.

Other Activities:

1. Tutored Particle Physics course instructed by Dr Santosh Rai during January-May, 2017.

Ratul Mahanta

Research Summary:

During the first half of the Acdemic year 2016-2017, I have done a big project under Dr. Anshuman Maharana and a small project under Dr. Dileep Jatkar on Conformal field theory and String theory, respectively. During this time I have covered first six chapters of the book on Conformal Field Theory by Philippe Di Francesco et al. and first two chapters of the book on String theory by Polchinski, Vol. 1. During the second half I have studied conformal field theory further, mainly covering 7th-10th chapter of Francesco's book on CFT, and used those techinques which I have learned, to reproduce the results of an article written by Alexander Maloney et al. Also I have attended a school, organised by Institute of Physics, Bhubaneswar at Puri during 12/02/2017 to 18/02/2017 on the following topics: Conformal Bootstrap, Symmetries of Perturbative Quantum Gravity, Black hole dynamics at Large D, Entanglement in QFT, Entanglement Entropy and Black Hole Thermodynamics.

Conference/Workshops Attended:

1. *Advanced String School*, Puri, India, Februray, 2017.

Ajanta Maity

Research Summary:

During the last one year I have studied metal/monolayer black phosphorus and metal/monolayer blue phosphorus interface properties using first-principle method. I have studied the change in the carrier (electron, hole) mobility in phosphorene as a function of uniaxial strain and uniaxial stress in x and y direction.

Being a stable allotrope of phosphorus, the 2-dimensional monolayer black phosphorus is used in different electronic devices. Monolayer blue phosphorus is also a new epitaxially grown stable allotrope of phosphorus. Both monolayer black phosphorus and monolayer blue phosphorus are semiconductors. Metals are used as electrode and form contact with semiconductor in electronic devices. For 2D materials, the metal-semiconductor interface properties decide the charge carrier injection efficiency from metal to semiconductor. To understand the contact behaviour, I have studied the interface of black phosphorus and blue phosphorus with different metals.

The low index surfaces of four metals Pd, Au, Ti and Ni are selected for metal/ monolayer black phosphorus (blak phosphorene) study. The surfaces Pd(111), Pd(110), Pd(100), Ni(110), Ti(0001), and Au(110) have lowest lattice mismatch with black phosphorus. I have studied the contact behaviour, barrier height etc. at the metal/black phosphorene interface. To understand the contact behaviour, I have used semi empirical Schottky-Mott model. Interestingly I have found that Pd(111) and Pd(110) make ohmic contact for holes. Other surfaces shows Schottky contact for both holes and electrons. The tunnel barrier height for these metals are found to be zero except Au(110). For monolayer blue phosphorus (blue phosphorene) I have used Pd(111),Pd(110),Pd(100), Au(110), Ni(100) and Al(111). There is finite Schottky barrier height (SBH) comes for both electrons and holes for all metals except that zero electron SBH comes for Al(111). The tunnel barrier height is zero for Ni(100) and Pd(111) surface. For other metal/blue phosphorene interfaces tunnel barrier height comes finite.

To study mobility due to strain engineering in phosphorene I have considered two cases one is uniaxial strain and another is uniaxial stress. The important result I have found is that the electron mobility is highest when strain is given along the armchair direction of phosphorene and the transverse (zigzag) direction is relaxed. On the other hand the hole mobility is highest when strain is given along zigzag direction and the armchair direction is fixed.

Band structure of the crystal is an important factor to calculate mobility. Whatever calculations I have done so far was by using GGA-PBE exchange correlation functional. I am currently studying the effective mass and mobility of phosphorene using another exchange-correlation functional HSE06.

Publications:

1. International Journal of Modern Physics B Vol 31, No 11 (2017) Density functional study of metal-phosphorene interfaces Ajanta Maity and Prasenjit Sen

Preprints:

1. Authors and co-authors name, *Title of the paper,* eprint number,if any.

2. Authors and co-authors name, *Title of the paper,* write (in preparation) if it does not have any preprint number.

Visits to other Institutes:

1. SN Bose National Center for Basic Science Kolkata, West Bengal, India

Dibya Kanti Mukherjee

Research Summary:

I have studied transport in Weyl semimetal-superconductor heterostructures. The primary goal was to study the effect of the chiral nature of the Weyl nodes in the Brillouin zone in transport phenomenon. For this we studied transport in a WIS geometry where the I refers to a Weyl semimetal with a barrier. This geometry demonstated both Klein tunneling and presence of chiral nodes play important roles as the conductance oscillated as functions of both the barrier height and the separation of the nodes in the Brillouin zone.

I have also studied a NWN geometry where the N refers to a normal lead characterized by a constant self energy matrix. The current oscillated as function of the separation between the Weyl nodes. We also found additional selection rules to determine the possible scattering from one Weyl node to another due to the symmetries of the problem.

I have also studied andreev spectroscopy of a Silecene layer which is irradiated by a high frequency light. It shows a non zero spin conductnace whose magnitude can be modulated by the amplitude of the driving.

Conference/Workshops Attended:

1. *School on Current Frontiers in Condensed Matter Research*, ICTS Bangalore, June, 2016.

Visits to other Institutes:

1. IIT, Kanpur, December, 2016.
2. IIT, Kanpur, January, 2017.

Chiranjib Mukhopadhyay

Research Summary:

I have worked on three areas of quantum information science in the last year.

With other collaborators, I have worked on a specific non-Markovian fermionic spin bath system with the aim of deriving and using a simple Lindblad type master equation in lieu of the time nonlocal integro-differential master equations available in literature. This was initially accomplished in the limit of infinite bath temperature. Moreover, we have recently succeeded in extending our results to arbitrary bath temperatures as well. Armed with this master equation,we have studied the phenomenon of equilibration in this strongly non-Markovian model. We have also shown the existence of certain resonance conditions for which the long time averaged state of this system is coherent. In future, we hope to study the dynamics of closely related systems to gain a better understanding of the role played by non-Markovianity in equilibration of systems exposed to thermal baths.

My second area of research has been the resource theory of quantum coherence. Along with collaborators from I.I.I.T. Hyderabad, I have shown that the robustness of quantum coherence behaves differently from other canonical measures of quantum coherence for multipartite systems. In another work performed with collaborators from my institute, I have tried to extend the quantitative description of quantum coherence from the usual orthonormal bases to more general non-orthogonal but linearly independent bases. Interesting implications for this have been obtained in the qubit case.

Lastly, I have been working on quantum thermodynamic machines. We have viewed the finite time performance of quantum absorption refrigerators through the lens of quantum speed limits and obtained novel bounds on cooling rate of such refrigerators analogus to the Curzon Ahlborn type bounds in literature , which have been derived for the case of cycle-based quantum thermal machines. These results may be of significant interest to the community in the sense that our formalism may be followed to study bounds on finite time performance of arbitrary thermal devices, including but not confined to thermal diodes and transistors, autonomous clocks etc., in a simpler way.

Publications:

1. Samyadeb Bhattacharya, Avijit Misra, Chiranjib Mukhopadhyay, Arun Kumar Pati, *Exact master equation for a spin interacting with a spin bath: Non-Markovianity and negative entropy production rate* , Physical Review A **95**, 012122, (2017).

Preprints:

1. Chiranjib Mukhopadhyay, Sreetama Das, Samyadeb Bhattacharya, Aditi Sen (De), Ujjwal Sen, *Quantum coherence in superposition with non-distinguishable pointers,* arXiv 1705.04343

2. Chiranjib Mukhopadhyay, Samyadeb Bhattacharya, Avijit Misra, Arun Kumar Pati, *Dynamics and thermodynamics of a central spin immmersed in a spin bath,* arXiv

1704.08291

3. Chiranjib Mukhopadhyay, Udit Kamal Sharma, Indranil Chakrabarty, *A note on robustness of coherence for multipartite quantum states,* (in preparation)

4. Chiranjib Mukhopadhyay, Samyadeb Bhattacharya, Avijit Misra, Arun Kumar Pati, *Quantum speed limit constrains the cooling rate of a quantum absorption refrigerator,* (in preparation)

Conference/Workshops Attended:

1. *Physics and Applied Mathematics Researchers' Meet (PAMRM) 2017*, Indian Statistical Institute, Kolkata, India, March, 2017 (Delivered Talk).

2. *Recent Trends in Quantum Theory (RTQT) 2017*, University of Calcutta, India, March, 2017 (Delivered Talk).

3. *Young Quantum (YouQu) 2017*, Harish Chandra Research Institute, Allahabad , India, February/March, 2017 (Delivered Talk).

4. *2nd IMSc School on Quantum Information*, Institute of Mathematical Sciences, Chennai, India, December, 2016.

Visits to other Institutes:

1. International Institute of Information Technology , Hyderabad, India, July/Aug, 2016.

Dipyaman Pramanik

Research Summary:

Neutrino oscillation physics has reached its precision era. Among the 6 oscillation parameters, Δm^2_{21},θ_{12}, θ_{13} have been measured with high precision and we also know the $|\Delta m^2_{31}|$ with good precision. We currently don't know the δ_{CP} .i.e. whether there is any CP violation in the leptonic sector or not, sign of the Δm^2_{31} .i.e. the mass-hierarchy and whether θ_{23} is greater than 45^o or less than 45^o or equal to 45^o.i.e. the octant. The future long baseline experiments are proposed in order to address these questions. But There might be some problems with their measurements if there exists new physics beyond standard oscillation paradigm. Two such new physics scenarios are light sterile neutrino and invisible neutrino decay. We have tried to see what happens if there are any of these new physics in nature to the future experiments like DUNE, T2HK and T2HKK. DUNE is a future long baseline experiment proposed to be built in USA. It will consist of a source at Fermilab and a detector of mass 40 kt at Sanford Underground Research Facility in South Dakota, This will have a baseline of 1300 km. T2HK will the upgrade version of the current T2K experiment from Tokai to Kamiokande in Japan at 295 km baseline. T2HKK is an alernative to the T2HK, where one of the water tank of the Hyper-kamiokande will be shifted to Korea at 1100 km baseline.

In one work we have considered the effect of sterile neutrino in DUNE, T2HK and T2HKK. Here we have studied the CP violation sensitivity, mass-hierarchy sensitivity and octant sensitivity in presence of sterile new for the individual experiments and also for the combination of DUNE and T2HK and DUNE and T2HKK. We have seen that if sterile neutrino is present in nature, the CP violation sensitivity is highly affected due to its presence. We also saw similar effect for the mass-hierarchy and octant also.

In another work we have investigated the effect of invisible decay of the third mass-eigenstate of the neutrino in DUNE. We have found the sensitivity to measure decay at DUNE, discovery potential at DUNE for decay and we have predicted the limit from DUNE if the neutrinos are stable. We also saw that the presence of decay can affect the measurement of θ_{23} severely and thus the octant sensitivity of DUNE. However we saw very small effect for the mass hierarchy sensitivity and almost none for CP violation sensitivity in presence of decay.

Publications:

1. Sandhya Choubey and Dipyaman Pramanik, *Constraints on Sterile Neutrino Oscillations using DUNE Near Detector,* Phys. Lett. **B764**, 135-141, (2017).

2. Mattias Blennow, Sandhya Choubey, Tommy Ohlsson, Dipyaman Pramanik and Sushant K. Raut *A combined study of source, detector and matter non-standard neutrino interactions at DUNE,* JHEP **1608**, 090, (2016).

Conference/Workshops Attended:

1. *Invisibles16-school and workshop*, Italy, September, 2016.
2. *xxii dae-brns high energy physics symposium*, India, December, 2016.

Other Activities:

1. Numerical Methods (Teaching Assistant), Aug-Dec, 2016.

Samiran Roy

Research Summary

During the period of last one year (from April 2016 to March 2017), I have studied the effects of non-unitarity (NU) on neutrino propagation through matter. The presence of heavy neutral fermions make the lepton mixing matrix (U_{PMNS}) non-unitarity. This will have effect on the determination of the present unknown of neutrino oscillation parameters such as mass hierarchy. We have studied the effect of NU, on the determination of the mass hierarchy at long baseline experiments. We are also trying to see the effect of neutral current in presence of extra light sterile neutrino at DUNE. Using neutral current, we can constrain the sterile parameters (e.g θ_{34}) with great accuracy.

Publications

1. Debajyoti Dutta, Pomita Ghoshal, Samiran Roy, Effect of Non Unitarity on Neutrino Mass Hierarchy determination at DUNE, NOνA and T2K, Nucl.Phys. B920 (2017) 385-401 (arXiv:1609.07094)

Saptarshi Roy

Research Summary:

During the academic year 2016-17, our research was mainly focussed in the study of multipartite quantum entanglement. In particular, we studied how entanglement is shared between the various parties in a multiparty scenario. In such a setting, monogamy of quantum correlations plays a key role as it restricts arbitrary sharing of entanglement between the various parties of a multiparty quantum state. However, these restrictions can be turned into an advantage and it was shown that monogamy of entanglement has several practical applications in a variety of areas of quantum information science including quantum cryptography. In this sense, monogamous states can be thought of as a useful resource in quantum communication between several parties. However, there exists multiparty quantum states which are non monogamous for a given quantum correlation measure.

In our work, we prove that an arbitrary quantum state which is nonmonogamous for negativity will become monogamous if a finite number of copies of the same state is provided. We refer this as activation of nonmonogamous states. We also show that multiple copies of a state satisfy monogamy for negativity if it does so for a single copy. The results are true for all quantum states of an arbitrary number of parties. Moreover, we find that two different three-qubit pure states which individually violate monogamy relation for negativity, taken together can satisfy the three-party monogamy relation. This holds for almost all three-qubit pure states while it is true for all three-qubit pure states when a four-party monogamy relation is used to check for their activation. We finally connect monogamy of negativity with genuine multipartite entanglement.

Preprints:

1. Saptarshi Roy, Tamoghna Das, Asutosh Kumar, Aditi Sen De, Ujjwal Sen, *Activation of Nonmonogamous Multipartite Quantum States*, arXiv:1608.06914.

Conference/Workshops Attended:

1. *International conference on Quantum Foundations*, India, October, 2016. Presented a poster titled as *Activation of Nonmonogamous Multipartite Quantum States.*

2. *Young Quantum*, India, February, 2017. Presented a poster titled as *Monogamy of Quantum Correlations.*

Other Activities:

1. Served as the tutor, Condensed Matter Physics 2 course, Jan-May semester, 2017.

Sudipto Singha Roy

Research Summary:

Quantum networks are an integral component in performing efficient computation and communication tasks that are not accessible using classical systems. A key aspect in designing an effective and scalable quantum network is generating entanglement between its nodes, which is robust against defects in the network. We consider an isotropic quantum network of spin-1/2 particles with a finite fraction of defects, where the corresponding wave function of the network is rotationally invariant under the action of local unitaries, and we show that any reduced density matrix also remains unaltered under the local actions. By using quantum information-theoretic concepts like strong subadditivity of von Neumann entropy and approximate quantum telecloning, we prove analytically that in the presence of defects, caused by loss of a finite fraction of spins, the network sustains genuine multisite entanglement, and at the same time may exhibit finite moderate-range bipartite entanglement, in contrast to the network with no defects.

We consider a generalized double Jaynes-Cummings model consisting of two isolated two-level atoms, each contained in a lossless cavity, with the cavities interacting with each other through a controlled photon hopping mechanism. The temporal dynamics of entanglement between the two atoms, as the atom-cavity system evolves with time, is investigated for different values of the mediated cavity-cavity interaction. We analytically show that at low values of such an interaction, entanglement between the atoms evolves under the effects of cavity perturbation and exhibits the well-known phenomenon of entanglement sudden death. Interestingly, using moderately large values of the interaction, a complete preclusion of sudden death of entanglement can be achieved, irrespective of its value in the initial two-atom state. Our results, thus allow us to design a model to sustain bipartite entanglement between two atomic qubits under the adverse effect of cavity induced environmental perturbation, by introducing a non-intrusive inter-cavity photon exchange that can be physically realized through cavity-QED setups in contemporary experiments. For completeness, we also compare the effects of inter-cavity interaction on entanglement with the case of direct spin-exchange interaction between the two isolated atoms.

Phase transition in quantum many-body systems inevitably causes changes in certain physical properties which then serve as potential indicators of critical phenomena. Besides the traditional order parameters, characterization of quantum entanglement has proven to be a computationally efficient and successful method for detection of phase boundaries, especially in one-dimensional models. Here we determine the rich phase diagram of the ground states of a quantum spin-1/2 XXZ ladder by analyzing the variation of bipartite and multipartite entanglements. Our study characterizes the different ground state phases and notes the correspondence with known results, while highlighting the finer details that emerge from the behavior of ground state entanglement. Analysis of entanglement in the ground state provides a clearer picture of the complex ground state phase diagram of the system using only a moderate-size model.

We review concepts and methods associated with quantum discord and related topics. We also describe their possible connections with other aspects of quantum information and beyond, including quantum communication, quantum computation, many-body physics, and open quantum dynamics. Quantum discord in the multiparty regime and its applications are also discussed.

Publications:

1. Tamoghna Das, Sudipto Singha Roy, Shrobona Bagchi, Avijit Misra, Aditi Sen De, Ujjwal Sen, *Generalized Geometric Measure of Entanglement for Multiparty Mixed States,* Phys. Rev. A **94**, 022336, (2016).

2. Debasis Sadhukhan, Sudipto Singha Roy, Amit Kumar Pal, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Multipartite Entanglement Accumulation in Quantum States: Localizable Generalized Geometric Measure,* Phys. Rev. A **95**, 022301 (2017).

3. Asutosh Kumar, Sudipto Singha Roy, Amit Kumar Pal, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Conclusive Identification of Quantum Channels via Monogamy of Quantum Correlations,* Phys. Lett. A **80**, 3588 (2016).

Preprints:

1. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Response to defects in multi- and bipartite entanglement of isotropic quantum spin networks* , arXiv:1607.05195 (2016).

2. Mahasweta Pandit, Sreetama Das, Sudipto Singha Roy, Himadri Shekhar Dhar, Ujjwal Sen, *Effects of cavity-cavity interaction on the entanglement dynamics of a generalized double Jaynes-Cummings model*, arXiv:1612.01165 (2016).

3. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Detecting phase boundaries of quantum spin-1/2 XXZ ladder via bipartite and multipartite entanglement transitions*, arXiv:1612.06831 (2016).

4. Anindita Bera, Tamoghna Das, Debasis Sadhukhan, Sudipto Singha Roy, Aditi Sen De, Ujjwal Sen, *Quantum discord and its allies: a review*, arXiv:1703.10542 (2017).

Conference/Workshops Attended:

1. *National Symposium On Recent Trends in Quantum Theory 2017(RTQT17)*, University of Calcutta, Kolkata, India, March, 2017.

2. *Young Quantum-2017* , HRI, India, February, 2017.

3. *Conference on Entanglement and Non-Equilibrium Physics of Pure and Disordered Systems*, ICTP, Trieste, Italy, July, 2016.

Visits to other Institutes:

1. International Centre for Theoretical Physics, Trieste, Italy, July, 2016.

2. Scuola Normale Superiore,Pissa, Italy, July, 2016.

Invited Lectures/Seminars:

1. *Analytical recursive method to ascertain multisite entanglement in doped quan- tum spin ladders* International Centre for Theoretical Physics, Trieste, Italy, July, 2016.

2. *Analytical recursive method to ascertain multisite entanglement in doped quan- tum spin ladders* Scuola Normale Superiore,Pissa, Italy, July, 2016.

Other Activities:

1. Member of the organizing committee, You-Qu 17, HRI, India, February, 2017.

2. Did tutorship of quantum information and computation course at HRI, Allahabad, for the period Jan-May 2017.

Tanaya Ray

Research Summary:

In the last year I have been working on parametrized tight binding model. Initially the tight binding hamiltonian of fcc silicon was calculated analytically and solved numerically to obtain the band structure with given values of the parameters ,which were then optimized to reproduce reliable band-gap with the help of the band-structure of Si obtained using DFT. Similar works were done for Phosphorene, Bismath and Stibium. In each case the band gap calculated using the optimized tight-binding parameters were reliable.

Currently, my research work is focused on developing a transferable tight binding model for metals and transition metals with the help of ab-initio results. Nowadays, a large number of such calculations is performed within the ab-initio approach utilizing the density functional theory, which proved to be very successful for the description of electronic structure properties of various materials. DFT works very effiently for bulk material, surface, small molecules or small clusters. However, DFT becomes extremely expensive for clusters containing thousands atoms or extended systems like nanowires. For this purpose we need an accurate and effective physical model. It would be desirable to have a simple model, which contains the essential physics necessary for a description of complex magnetic structures, powerful enough to enable the possibility for a diverse analysis of the results in terms of various parameters of considered systems, such as spin-orbit coupling strength, spin polarization, electron occupation, degree of hybridization between the electronic orbitals,various symmetries etc. Tight Binding model offers such an efficient description which contains the essential physics and is also computationaly less expensive than DFT.

The parametrized tight-binding method, implemented, is designed for this purpose. The material-specific parameters entering this method provide an easy way to tune the aforementioned essential quantities. This method allows to perform a lot of comparatively fast calculations in combination with a freedom to vary important properties of the magnetic system. For this purpose I have started developing a code to optimize the parameters for Rh.

Shouvik Roychoudhury

Research Summary:

During academic year 2016-2017 I have been working with Dr Sandhya Choubey on the effect of presence of light (eV scale) thermal sterile neutrinos on Cosmology. Standard model of particle physics includes three massless active neutrinos and corresponding anti-neutrinos. However, neutrino oscillation experiments over the year have strongly suggested oscillation among the active neutrino species, leading to small but different masses of the three different spieces. Moreover, several anomalies in short baseline neutrino oscillation experiments can be explained with more than three neutrino species and hence there is a considerable amount of interest in models with extra species of sterile neutrinos of mass around 1 eV which mix with the three active neutrinos and are uncharged under the standard model gauge group. We are exploring the sterile neutrino situation from cosmological perspective, using combination of latest data sets available. In particular, we are using Planck 2015 data release for CMB and the BK14 data release from the BICEP-Keck collaboration, along with the Baryon Acoustic Oscillations (BAO) data and latest prior on the Hubble constant from direct measurements (HST). We are using CosmoMC for running Markov Chain Monte Carlo chains and analysing them. We find that inclusion of BK14 data worsens the viability of a fully thermalised eV scale sterile neutrino. The pre-print for this work is in preparation.

We are also continuing our work on the potential of eV-scale sterile neutrinos with self-interactions mediated by an MeV scale gauge boson in solving the problem of having a low value of effective number of relativistic species of neutrinos (which is preferred by the datasets). Also, the same gauge boson can be conjectured to mediate self-interactions among dark matter particles as well as interactions between sterile neutrinos and dark matter particles which has potential to solve some long standing problems in cosmological structure formation and we are currently conducting research on that also.

Preprints:

1. Shouvik Roychoudhury, Sandhya Choubey, *Light Sterile Neutrinos in Cosmology: Analysis with BK14 Data* (in preparation)

Conference/Workshops Attended:

1. *DAE-BRNS High Energy Physics Symposium*, India, December, 2016.

2. *SERC THEP Main School*, India, January, 2017.

Debasis Sadhukhan

Research Summary:

The idea of an isolated system is impractical in nature due to environmental interactions. Quantum correlations among the parts of a many-body system are known to decay rapidly with time, thus making a quantum information processing protocol impossible to run for a longer time. Quantum discord, an information theoretic measure of quantum correlation, has been shown to freeze over time under different noise models. However, entanglement is arguably more useful than quantum discord in realizing the QIP protocols. Scientists over the globe are trying to identify situations in anopen system scenario, where entanglement remains fixed for a reasonable large time. We show that bipartite entanglement can be frozen over time with a proper choice of the many-body substrate, namely the 1D anisotropic XY model in alternating transverse field, which is in contact with environment. We also show that in the dimer and the paramagnetic phases of the system, the length of the freezing interval, for a chosen pair of nearest-neighbor spins, is independent of the length of the spin-chain, indicating a scale-invariance. This allows us to propose a relation between the length of the freezing interval and the distance of the chosen pair of spins with the environment.

There exist zero-temperature states in quantum many-body systems that are fully factorized, thereby possessing vanishing entanglement, and hence being of no use as resource in quantum information processing tasks. Such states can become useful for quantum protocols when the temperature of the system is increased, and when the system is allowed to evolve under either the influence of an external environment, or a closed unitary evolution driven by its own Hamiltonian due to a sudden change in the system parameters. Using the one-dimensional anisotropic XY model in a uniform and an alternating transverse magnetic field, we show that entanglement of the thermal states, corresponding to the factorization points in the space of the system parameters, revives once or twice with increasing temperature. We also study the closed unitary evolution of the quantum spin chain driven out of equilibrium when the external magnetic fields are turned off, and show that considerable entanglement is generated during the dynamics, when the initial state has vanishing entanglement. We also find that creation of entanglement for a pair of spins is possible when the system is made open to an external heat bath, interacting through that spin-pair having a repetitive quantum interaction.

In another work, we compare the effect of annealed disorder and quenched disorder on quantum spin systems. We investigate bipartite entanglement in random quantum XY model at equilibrium. Depending on the intrinsic time scales associated with the equilibration of random parameters and experimental measurements, we consider two distinct kinds of disorders, namely annealed and quenched disorders. The primary interest of this work is to conduct a comparative study for understanding the affects of disorder on nearest-neighbor entanglement, as the nature of randomness changes from annealed to quenched. We find that entanglement properties of the annealed and quenched disordered sys- tems are drastically different from each other. In particular, while quenched disordered system is always entangled and may be bestowed with enhanced amount of entanglement in comparison to the homogeneous system in large parameter stretches, annealed disorder always shrinks the value of entanglement and may even cause it to vanish in specific parametric regime. Subjecting the random system with varying disorder strengths, we identify the entangled-separable phases in the annealed disordered systems and enhanced-normal phases in the quenched disordered systems.

Besides working on orginal problems, we have also writen a review on quantum discord, a information-theoretic quantum correlation measure, during the current academic year. We have also described their possible connections with other aspects of quantum information and beyond, including quantum communication, quantum computation, many-body physics, and open quantum dynamics. Quantum discord in the multiparty regime and its applications are also discussed.

Publications:

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

2. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, Ujjwal Sen, *Static and dynamical quantum correlations in phases of an alternating field XY model,* Phys. Rev. A **94**, 042310, (2016).

3. Debasis Sadhukhan, Sudipto Singha Roy, Amit Kumar Pal, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Multipartite entanglement accumulation in quantum states: Localizable generalized geometric measure,* Phys. Rev. A **95**, 022301, (2017).

Preprints:

1. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen (De) and Ujjwal Sen, *Scale-invariant freezing of entanglement,* arXiv:1610.00730.

2. Anindita Bera, Tamoghna Das, Debasis Sadhukhan, Sudipto Singha Roy, Aditi Sen (De) and Ujjwal Sen, *Quantum discord and its allies: a review,* arXiv:1703.10542.

3. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen (De) and Ujjwal Sen, *Emergence of entanglement with temperature and time in factorization-surface states,* arXiv:1705.09812.

4. Anindita Bera, Debasis Sadhukhan, Debraj Rakshit, Aditi Sen (De) and Ujjwal Sen, *Entanglement in Random XY Model: Annealed vs. Quenched Disorder* (in preparation).

Conference/Workshops Attended:

1. *Young Quantum-2017*, HRI, Allahabad, India, February, 2017
Presented a Talk titled 'Statics and dynamical quantum correlations in phases of an alternating transverse field XY model'.

2. *Conference on Entanglement and Non-Equilibrium Physics of Pure and Disordered Systems*, ICTP, Trieste, Italy, July, 2016.

3. *Conference on Long-Range-Interacting Many Body Systems: from Atomic to Astrophysical Scales*, ICTP, Trieste, Italy, July, 2016
Presented a Poster titled 'Enhancement of Quantum Correlation Length in Quenched Disordered Spin Chains'.

Visits to other Institutes:

1. University of Siegen, Siegen, Germany, July, 2016.

2. CMSP Section, ICTP, Trieste, Italy, August, 2016.

3. University of Freiburg, Freiburg, Germany, August, 2016.

Lectures/Seminars:

1. *Statics and Dynamical Quantum Correlations in Inhomogeneous Transverse Field XY Model*, Condensed Matter Physics Seminar, CMSP Section, ICTP, Trieste, Italy, August, 2016.

Other Activities:

1. Member of local organizing committee of Young-Quantum-17, Harish-Chandra Research Institute, February, 2017.

Biswajit Sahoo

Research Summary:

In the academic year 2016-2017 I am studying a problem in supervision of Prof. Dileep Jatkar on finding local conformal generators for D>2 CFT and using it whether we can organize infinite number of primary fields into a finite number of conformal families mimicking D=2 CFT case. We are attacking the problem from various perspective such as constructing level-2 CFT spectrum generator demanding existence of null vector at level-2. Another way of organizing infinite number of primaries is observing the scaling dimensions of primaries for a particular theory say, N=4 SYM theory in 4D and trying to make naive guess on the spectrum generating algebra for D>2 CFT.

Conference/Workshops Attended:

1. *School and Workshop on Modular forms and Black Holes*, India, January, 2017.

2. *Advanced String School, IOP*, India, February, 2017.

Visits to other Institutes:

1. National Institute for Science Education and Research, Bhubaneswar, India, May-June, 2016.

Other Activities:

1. Presenting two group talks on 4D N=1 Supersymmetry, July-August, 2016.

2. Reading project on D>2 CFT in supervision of Prof. Dileep Jatkar, Aug-Dec, 2016.

3. Reading Project on Basic String Theory in supervision of Prof. Anshuman Maharana , Aug-Dec, 2016.

4. Presenting Journal Club talk on Conformal BMS, March, 2017.

5. Auditing and tutoring Quantum Field Theory-II course taught by Prof. Ashoke Sen, January-March, 2017.

6. Audited course Conformal Field Theory taught by Prof. Anirban Basu , August-December, 2016.

Ruchi Saxena

Research Summary:

I am currently working on the following projects -

1. Time-dependent periodically driven topological systems with spin-orbit coupling

   Here, we study the Dirac system with spin-orbit coupling in presence of circularly polarised light (CPL). We take silicene as our model which is a topological insulator. It is interesting to study its topological phasess in non-equilibrium environment.We get nobel topological phases unlike the static case.

2. Realization of Higher Haldane Model from BW Hamiltonian of SO coupled Dirac systems

   Here, we want to study the long range hopping consequenses of BW Hamiltonian of spin-orbit coupled Dirac systems. Specifically, we want to realize the higher Haldane Model from high frequency expansion of irradiated SO coupled systems like silicene, Germanene etc.

Future Research Plan

1. Blockage of Andreev reflection for N=0 Landau level in the geometry of SC-N-SC, made up of graphene where the extreme ends are the contacts

2. Study the transport of FSF junction made up of systems with SO-coupling when one of the region is exposed to light

3. Study the Green's function approach to study the junction transport

Publications:

1. Priyanka Mohan, Ruchi Saxena, Arijit Kundu, Sumathi Rao *"BrillouinWigner Theory for Floquet Topological Phase Transitions in Spinorbit Coupled Materials"*, Phys. Rev. B **94**, 235419, (Published on 16 December 2016)

Sandeep Kumar Sehrawat

Research Summary:

Over the last academic year (April 2016-March 2017), I studied the search for the Dark Matter Particle in the fixed target neutrinos experiments. Dark Matter particle composed of the 80% matter content of the universe according to standard model of Cosmology and understanding it's particle nature is one of the major problem in modern theoretical Physics. We also studied the possible signature of the Beyond Standard Model Physics like Non Unitarity, Equivalence Principle violation, Lorentz Violation etc. in Neutrino Long baseline experiments. In standard neutrino oscillation scenario, we assume the Neutrino mixing matrix to be unitary; in our work we explore the effect of non-unitarity of this matrix on the determination of the octant of θ_{23} angle of mixing matrix, which is one of the major problem in Neutrino Physics.

Publications:

1. Debajyoti Dutta, Pomita Ghoshal, Sandeep K. Sehrawat, *Octant of θ_{23} at long baseline neutrino experiments in the light of Non Unitary Leptonic mixing*, Phys. Rev. D 95, 095007 (2017).

Conference/Workshops Attended:

1. *XXII DAE-BRNS HIGH ENERGY PHYSICS SYMPOSIUM 2016, December 12-16, 2016 - University of Delhi*

Arpita Sen

Research Summary:

My research topic is the study of free and ssurface supported atomic clusters using first principle electronic calculation.

Clusters are the collection of atoms. Unlike bulk they are finite objects. For simple metal clusters if we consder the interaction between the valence electrons and the nucleii are spherically symmetric the electronic energy levels occur in bunches and they are as 1S ,1P ,1D ... in increasing order. Like nuclear shell model magic number behavior is found in clusters. Clusters that mimic the properties of atoms are called 'superatoms'. The experiment showed that cluster with one electron less than shell filling has large electron affinity like halogen atoms. The cluster has one electron more than shell filling has less ionization potential like alkali atoms.

As the metal clusters mimic such properties so the question arises that whether they obey the Hund's rule of maximum spin multiplicity, i.e for partially filled shells whether the highest total spin is the lowest energy state. If so then the cluster systems will be magnetic in ground state but they are nonmagnetic in bulk. Possibility of such magnetic ground state in alkali clusters has been predicted in DFT and is intriguing.

But in DFT there is some approximation by the exchange correlation term. So to find more accuracy some higher level of theory is required

I perform Quantum Monte-Carlo calculation for cesium cluster and also compare the results with that obtained from DFT calculation.

I am working on Silicon atom caged Tantalum cluster to study its super atomic behaviour on highly oriented polytropic graphite surface. I have studied its properties on the substrate at zero tempearture and also at finite temperature by ab initio molecular dynamics simulation.

Recently theories and experiments have shown magnetic anisotropy energy in cobalt clusters can be significanty increased by doping it with non magnetic atoms like carbon. I am studying about the origin of increase of anisotropy energy of these systems using first principle DFT calculation.

Md Arif Shaikh

Research Summary:

I have been mostly working on the emergence of curved acoustic manifold otherwise known as analogue gravity phenomenon in the context of astrophysical black hole accretion. I have worked on three different projects related to this subject which I will discuss briefly here. Apart from these I have spent a considerable time in studying nonlinear time series analysis of the accretion light curve which is a tool to investigate the chaotic signature in the light curve. Recently I have started working on traversable wormhole solutions.

1. Analogue gravity by perturbing Bernoulli's constant: In literature most of the studies on analogue gravity phenomena are done by linear perturbation of velocity potential of the fluid, where the fluid is considered to be ideal inviscid and irrotational. Recently it was shown that one can obtain the same acoustic spacetime metric by linear perturbing the mass accretion rate, which is a more perceptible quantity in the context of astrophysical accretion. We have shown that there is yet another quantity, namely the relativistic Bernoulli's constant, which can be linear perturbed to obtain the same acoustic metric. The relativistic Bernoulli's constant is the integral constant of the time independent relativistic Euler equation. We showed the above results for different system and flow geometries. We started from the most simple case, that is the Newtonian spherical accretion to demonstrate the same and did the same for other cases which are axially symmetric accretion in Newtonian case, spherical and axially symmetric accretion in Schwarzschild metric.

2. Relativistic sonic geometry for accretion in the **Schwarzschild metric:** In this work on analogue gravity phenomenon we studied the emergence of curved sonic manifold for accretion in the Schwarzschild metric. We first derived the relativistic Euler equation for a perfect fluid governed by different thermodynical equation of state. Assuming the fluid to be irrotational we derive the expression for the vorticity tensor in relativistic fluid. The irrotationality condition gives the velocity potential for relativistic fluid. Next we linear perturb this velocity potential as well as the relativistic Bernoulli's constant and the mass accretion rate to find the acoustic spacetime metrics which we found to be same up to a conformal factor. We did the analysis for both spherical accretion and axially symmetric accretion. Once we obtained the acoustic spacetime metric we studied different features of the acoustic space time. We first found the location of acoustic event horizon. For spherically symmetric accretion we found that the acoustic event horizon and the transonic surface, where the Mach number $\mathcal{M}$ is 1, coincide. For axially symmetric flow these two surfaces coincide for constant height flow and conical flow but differ for flow with hydrostatic equilibrium in vertical direction. We then studied the causal structure of the acoustic spacetime. To do this we solved the stationary relativistic Euler equation numerically and obtained $\mathcal{M}$ vs r as well as the causal structure $t(r)$ vs r plots. Finally we obtained the expression for acoustic surface gravity which is a measure of the analogue Hawking temperature. The acoustic surface gravity is obtained in terms of the background metric elements and the stationary integral solutions.

3. Relativistic sonic geometry for accretion in the Kerr metric: In the previuos work we assumed the background to be spherically symmtric static Schwarzschild metric.

However astronomers believe that most the black holes have non zero intrinsic spin a. Therefore we did the analysis mentioned in the previous paragraph for accretion in the Kerr metric. Here the acoustic spacetime metric elements contains the parameter a. All the studies done in the Schwarzschild case was studied here. In addition to that we studied effects of shock on the causal structure of the acoustic spacetime. We found that the introduction of a shock in the accretion allows the formation of an analogue white hole.

4. Nonlinear timeseries analysis of accretion light curve: In this project we study how the nonlinear timeseries analysis technique can be used to investigate for low dimensional chaotic signature in accretion light curves. The dynamics of accretion disk near the horizon is very complicated and is governed by many underlying processes which are difficult solve fully analytically. One way to build an analytical model is to first know the effective degrees of freedom of the system. Here the importance of the nonlinear timeseries analysis lies. This analysis takes any timeseries data and reconstructs phase space trajectories in different embedding dimensions. For each of these dimensions d, the correlation dimension D_2 of the reconstructed system is evaluated numerically using the Grassberger-Procaccia algorithm. If after some dimension $d = m$ the value of the correlation dimension does not change i.e it saturates to a value,say ν, then this saturated value of D_2 is taken to be the fractal dimension of the system. If we are able to find any such value of D_2 then it would imply that the system can be described effectively by ν number of degrees of freedom and therefore only ν numbers of equations are needed to describe the system effectively.

5. Comparative study of wormholes with charge with some density profiles of the galaxies: In this project we extend the Morris-Thorne wormhole solution to a general wormhole solution with static charge distribution, and some density profile of the galaxy, which is consistent with the observational profile of the galactic rotation curves.

Preprints:

1. Md Arif Shaikh, *Relativistic sonic geometry for isothermal accretion in the Kerr metric,* arXiv:1705.04918 [gr-qc].

2. Md Arif Shaikh, Ivleena Firdousi and Tapas K. Das, *Relativistic sonic geometry for isothermal accretion in the Schwarzschild metric,* arXiv:1612.07963 [gr-qc].

3. Satadal Datta, Md Arif Shaikh and Tapas K Das, *Acoustic geometry obtained through the perturbation of the Bernoulli's constant,* arXiv:1612.07954 [gr-qc].

Conference/Workshops Attended:

1. *35$^{\text{th}}$ Annual Meeting of the Astronomical Society of India (ASI)*, India, March, 2017.

2. *29th meeting of the Indian Association for General Relativity and Gravitation (IAGRG)*, India, May, 2017.

Visits to other Institutes:

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

Other Activities:

1. Tutored Electrodynamics course intructed by S. Naik, January - May, 2017.

Gautam Sharma

Research Summary:

In the last year I have worked on coherence disturbance complementarity relation. Disturbance of a quantum state is upper bounded by the amount of information that can be extracted from a system by a quantum measurement. Moreover quantum measurement also causes loss in coherence of the system. Quantum coherence is a resource which enables us to perform important information theoretic tasks. From the above facts we were motivated to think that there must be a trade-off between the two quantities. The work is nearly complete and will be submitted soon.
Along with this I have also been reading about the Contextuality problem. Also I have studied about various kind of uncertainty relations and have found a definition which can be very useful. Work on uncertainty relation is still going on. We are trying to find how the new uncertainty relation performs against the old uncertainty relation.

Preprints:

1. A.K.Pati and Gautam Sharma, *Complementarity Relation for Coherence and Disturbance*, (in preparation)

Conference/Workshops Attended:

1. *FPQP*, ICTS, Bengaluru, 21^{st} November to 10^{th} December, 2016.

2. *Young Qunatum* , HRI, Allahabad, 27^{th} February to 1^{st} March, 2017.

Other Activities:

1. Part of organizing committee of Young Quantum 2017 at HRI, February and March, 2017.

Mritunjay Kumar Verma

Research Summary:

In the acedemic year 2016-2017, I have been involved in mainly two projects. In the first project, we considered the world-sheet dual of the boundary CFT OPE coefficients. The main result of this project was a relation between the OPE coefficients in the boundary theory and the OPE coefficients in the world-sheet theory.

In the second project, we are considering the pure spinor formalism of supertring theory. We are trying to construct the unintegrated vertex operator for the first massive states in the string theory. In the period mentioned above, we succeded in obtaing the theta expansion of the superfields which appear in this vertex operator.

Along with above mentioned projects, we also published the work on the tree level Feynman rules in mellin space for CFTs.

Publications:

1. Amin A. Nizami, Arnab Rudra, Sourav Sarkar, Mritunjay Verma, *Exploring Perturbative Conformal Field Theory in Mellin Space*, JHEP **0701**, 102, (2017).

Preprints:

1. Sudip Ghosh, Sourav Sarkar, Mritunjay Verma, *Implications of the AdS/CFT Correspondance on Space-time and World-Sheet OPE Coefficients*, 1703.06132

2. Subhroneel Chakrabarti, Sitender Pratap Kashyap, Mritunjay Verma, *Theta expansion of first massive vertex operator in pure spinor,* (In preparation)

Visits to other Institutes:

1. Perimeter Institute of Theoretical Physics, Waterloo Ontario, Canada, July, 2016.

Samyadeb Bhattacharya

Research Summary:

Construction of exact master equation for a central spin without Weak coupling and Born-Markov approximations : An exact canonical master equation of the Lindblad form is derived for a central spin interacting uniformly with a sea of completely unpolarized spins. The Kraus operators for the dynamical map are also derived. The non-Markovianity of the dynamics in terms of the divisibility breaking of the dynamical map and increase of the trace distance fidelity between quantum states is shown. Moreover, it is observed that the irreversible entropy production rate is always negative (for a fixed initial state) whenever the dynamics exhibits non-Markovian behavior. In continuation with the study of witnessing non-Markovianity, it is shown that the positive rate of change of the purity of the central qubit is a faithful indicator of the non-Markovian information back flow. Given the experimental feasibility of measuring the purity of a quantum state, a possibility of experimental demonstration of non-Markovianity and the negative irreversible entropy production rate is addressed. This gives the present work considerable practical importance for detecting the non-Markovianity and the negative irreversible entropy production rate.
Dynamics and thermodynamics of a central spin immmersed in a spin bath : An exact reduced dynamical map along with its operator sum representation is derived for a central spin interacting with a thermal spin environment. The dynamics of the central spin shows high sustainability of quantum traits like coherence and entanglement in the low temperature regime. However, for sufficiently high temperature and when the number of bath particles approaches the thermodynamic limit, this feature vanishes and the dynamics closely mimics Markovian evolution. The properties of the long time averaged state and the trapped information of the initial state for the central qubit are also investigated in detail, confirming that the non-ergodicity of the dynamics can be attributed to the finite temperature and finite size of the bath. It is shown that if a certain stringent resonance condition is satisfied, the long time averaged state retains quantum coherence, which can have far reaching technological implications in engineering quantum devices. An exact time local master equation of the canonical form is derived . With the help of this master equation, the non-equilibrium properties of the central spin system are studied by investigating the detailed balance condition and irreversible entropy production rate. The result reveals that the central qubit thermalizes only in the limit of very high temperature and large number of bath spins.
Resource theory of quantum coherence for non-orthogonal states : The notion of quantum coherence for superpositions over states which are not necessarily mutually distinguishable, is proposed. This naturally leads to a resource theory of non-orthogonal coherence. Free states and free operations in this theory are characterized and the latter has been connected with free operations in the resource theory of quantum coherence for distinguishable bases. Existence of a unique maximally coherent qubit state corresponding to any given purity has been demonstrated.

Publications:

1. Samyadeb Bhattacharya, Avijit Misra, Chiranjib Mukhopadhyay and Arun Kumar Pati, *Exact master equation for a spin interacting with a spin bath: Non-Markovianity and negative entropy production rate,* Physical Review A **95**, 012122, (2017)

Preprints:

1. Chiranjib Mukhopadhyay, Samyadeb Bhattacharya, Avijit Misra and Arun Kumar Pati, *Dynamics and thermodynamics of a central spin immmersed in a spin bath,* arXiv:1704.08291

2. Chiranjib Mukhopadhyay, Sreetama Das, Samyadeb Bhattacharya, Aditi Sen De and Ujjwal Sen, *Quantum coherence in superposition with non-distinguishable pointers,* arXiv:1705.04343

Conference/Workshops Attended:

1. *2nd IMSc School on Quantum Information*, India, December 2016.

2. *Young Quantum*, India, February 2017.

3. *National Symposium On Recent Trends in Quantum Theory*, India, March 2017.

4. *Physics and Applied Mathematics Researchers' Meet*, India, March 2017.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, December 2016,

2. University of Calcutta, Kolkata, India, March 2017.

3. Indian Statistical Institute, Kolkata, India, March 2017.

Invited Lectures/Seminars:

1. *Exact master equation for a spin interacting with a spin bath*, Young Quantum, Harish-Chandra Research Institute, Allahabad, February 2017.

2. *Energy cost of creating coherence*, National Symposium On Recent Trends in Quantum Theory, Department of Applied Mathematics, University of Calcutta, Kolkata, March 2017.

3. *Exact master equation for a spin interacting with a spin bath*, Physics and Applied Mathematics Research Scholars Meet, Physics and Applied Mathematics Unit, Indian Statistical Institute, Kolkata, March 2017.

Debmalya Das

Research Summary:

I joined the Department of Physics, Harish-Chandra Research Institute (HRI) on 12th October, 2016 as a Postdoctoral Fellow. Following is the summary of the research work done between 12/10/2016-31/03/2017.

1. Quantum communication makes use of quantum channels and resources such as quantum entanglement to send information from one party to another. Protecting the original information (in the form of a state) from channel noise then becomes an important task, as far as the performance of the channel is concerned. We make use of various multipartite entangled states as channels and study their performances, relative to the standard procedure of quantum communication. We show that with certain channels, we can achieve higher fidelity than the standard protocol.

2. Uncertainty relation is an important aspect of quantum mechanics. In recent years, there is a renewed interest in the area concerning the interpretations of the quantities. There also have been many attempts to obtain more and more general formalisms of uncertainty. We introduce a novel approach in deriving uncertainty relation that, we believe, can be helpful in addressing certain states, previouly untouched by the existing relations. We also study the utility of our relation for states that can be easily dealt with the existing forms.

3. In thermodynamics, the idea of Szilard engine in the context of the Maxwell demon is of utmost importance. The quantum version of the Szilard engine exists in literature. However, we argue that the formalism has many shortcomings and introduce an approach consistent with quantum thermodynamics.

Conference/Workshops Attended:

1. *2nd International Conference on Quantum Foundations (ICQF) 2016*, India, October, 2016.

2. *Young Quantum 2017*, India, February and March, 2017.

Visits to other Institutes:

1. Indian Institute of Science Education and Research (IISER) Mohali, Mohali, India, November, 2016.

Other Activities:

1. Part of organizing committee of Young Quantum 2017 at HRI, February and March, 2017.

Debajyoti Dutta

Research Summary:

My work focuses on studying the capabilities of upcoming long-baseline accelerator neutrino experiment at Fermilab, U.S known as DUNE (Deep Underground Neutrino Experiment). This experiment is designed to determine the remaining unknowns in neutrino oscillation physics: 1) the mass hierarchy 2) leptonic CP violation and 3) octant of θ_{23} mixing angle. Presently, we focus on the effects of new physics at these experiments. If nature have fourth flavor of neutrinos which is popularly called sterile neutrino(s), then how the present generation of long baseline neutrino experiments can probe its oscillations. Presence of a light sterile neutrino can hamper the standard sensitivity measurements at these experiments. We have showed how sensitivity to CP violation as well as mass hierarchy gets affected if there is a light sterile neutrino. We have extended our sensitivity study to different world class accelerator experiments like NOvA, T2K, T2HK, T2HKK etc. If this sterile neutrino is very heavy to be detected in any oscillation experiments, then its presence will hamper the unitarity of the Leptonic mixing matrix. So we have recently studied the effect of non unitary Leptonic mixing matrix at the far detector of these experiments in details. We have also doing some work on possibility of excluding different neutrino mass textures at DUNE.

Publications:

1. Kalpana Bora, Gayatri Ghosh, Debajyoti Dutta, *Octant Degeneracy, Quadrant of leptonic CPV phase at Long Baseline Neutrino Experiments and Baryogenesis*, Adv.High Energy Phys. 2016 (2016) 9496758, arXiv:1606.00554.

2. Debajyoti Dutta, Raj Gandhi, Boris Kayser, Mehedi Masud, Suprabh Prakash, *Capabilities of long-baseline experiments in the presence of a sterile neutrino*, JHEP 1611 (2016) 122, arXiv:1607.02152.

3. Debajyoti Dutta, Pomita Ghoshal, *Probing CP violation with T2K, NOA and DUNE in the presence of non-unitarity*, JHEP 1609 (2016) 110, arXiv:1607.02500.

4. Debajyoti Dutta, Pomita Ghoshal, Samiran Roy, *Effect of Non Unitarity on Neutrino Mass Hierarchy determination at DUNE, NOA and T2K* , Nuclear Physics B, Volume 920, July 2017, Pages 385-401, arXiv:1609.07094.

5. Debajyoti Dutta, Pomita Ghoshal, Sandeep K. Sehrawat, *Octant of θ_{23} at long baseline neutrino experiments in the light of Non Unitary Leptonic mixing* , Physical Review D 95, 095007, arXiv:1610.07203.

Preprints:

1. Kalpana Bora, Debasish Borah, Debajyoti Dutta, *Probing Majorana Neutrino Textures at DUNE*, arXiv:1611.01097.

2. Sandhya Choubey, Debajyoti Dutta, Dipyaman Pramanik, *Imprints of a light Sterile Neutrino at DUNE, T2HK and T2HKK*, arXiv:1704.07269.

Conference/Workshops Attended:

International Neutrino Summer School in Vitenam, Quy Nhon, 17-29 July, 2016.

Manjari Gupta

Research Summary:

I have joined HRI on 18th November 2016 as a Post Doctoral Fellow in condensed matter physics. Since then I have started a research problem on *extended Bose-Hubbard model* with long range interaction, specifically dipole-dipole interaction. I am currently setting up a numerical scheme to solve the problem and get useful results. Meanwhile I am also working on finishing the papers for the work that I have done in my PhD.

Conference/Workshops Attended:

1. *Discussion Meeting on Nonequilibrium Quantum Many Body Physics*, HRI, Allahabad, India, 21-25 November, 2016.

Safiqul Islam

Research Summary:

A brief description of the research work during the academic year 2016-2017, *i.e*, 1st April 2016 to 31st March 2017, is given below:

1. A parametric model to study the mass radius relationship of stars : For relativistic charged fluid with the signature of pressure anisotropy, where the anisotropy is defined by the finite non zero difference between the radial and the tangential fluid pressure, the Einstein Maxwell field equations are solved for static spherically symmetric spacetime. Certain functional form of the electric field as well as the effective gravitational potential have been introduced in our model, where such field and potential are characterized by two free parameters a and b, with certain relationships defined between these two parameters, where such relationships are obtained using a particular form of stability criteria. The charge and the mass energy density have been expressed (as a consequence of the interior solution) as a function of the radial distance. From there, we obtain the mass-radius relationship for the interior solution. Once such mass-radius relationship is integrated for a particular limit defined by the radius of the star, one can obtain what will be the mass of the charged fluid considered in our model, embedded within a sphere of radius R. Hence our model here provides the mass M(R) of star of radius R. M(R) in our calculations, however, is characterized by (a,b), and there remains a specific relationship between a and b, which are obtained by using some prede- fined stability criterion. Various values of a and b provides various [M(R)-R] measurements. For different values of a and b, one can find M(R) for different values of R, and hence using our model, we can study the mass radius relation for different categories of stellar objects located at various regions of the Hertzsprung-Russel diagram.

2. A Reissner-Nordström+Λ black hole in the Friedman-Robertson-Walker universe: A charged, non-rotating, spherically symmetric black hole which has cosmological constant Λ (Reissner-Nordström+Λ or RN+Λ), active gravitational mass M and electric charge Q is studied with exterior Friedman-Robertson-Walker (FRW) universe in (2+1) dimensional spacetime. We find a new classes of exact solutions of the charged black hole where the generalized Birkoffs theorem is assumed to be valid. It is found that the cosmological constant is negative inside the black hole. We confirm it from the geodesic equations too. The cosmological constant is found to be dependent on R, Q and $a(v)$ which correspond to the areal radius, charge, of the black hole and the scale factor of the universe respectively. We note that the expansion of the universe affects the size and the mass of the black hole. An important observation is that, for an observer at infinity, both the mass and charge of black hole increase with the contraction of the universe and decrease with the expansion of the universe.

3. Model of a charged isotropic star in $f(R,T)$ gravity embedded in an exterior Schwarzschildt metric : We discuss the interior solutions of a charged and spherically symmetric distribution of fluid inside a sphere in $f(R,T)$ gravity which admits of conformal killing vectors. The charged sphere is embedded in the exterior Schwarzschildt metric. We assume that initially all physical quantities are in static equilibrium. The perfect fluid matter has been studied under a particular form of the Lagrangian density $f(R,T)$. The energy conditions as well as stability of the solutions

have been investigated in the background of $f(R,T)$ gravity and the blueshift of the star is discussed. Also the non-geodesic nature of the fluid body has been studied. The smooth matching conditions with the exterior Schwarzschildt metric have been briefed. $f(R,T)$ gravity is believed to explain the nature of Dark Energyand solve the mysteries pertaining to the expanding behaviour of the Universe in the gravitational phenomenon.

4. Comparative study of wormholes with charge under some density pro
files of galaxies : The existence of Lorentzian wormholes has been a speculative issue though there are views that it can exist at the planck scale of 10^{-35} metres. Though wormholes are designated as tunnels connecting two distinct universes or regions of the same universe but their actual physical significance was first proposed by Morris and Thorne and their possible locations in the galactic halo and central regions of galaxies further studied by Rahaman F. et al. Exact solutions of the wormhole with extra fields such as scalar field and static electric charge has been studied by Kim S.W et al. and derived self-consistent solutions. We are acquainted with the fact that wormhole spacetimes are predictions of the GTR and need to be supported by observations. The modified extended metric for the charged wormhole model of Kim and Lee has been developed by Kuhfittig P.K.F. to represent a charged wormhole that is compatible with quantum field theory. In this paper we thrive to derive a general metric of a charged wormhole under some density profiles of galaxies which should also be consistent with the observational profile of rotation curve of galaxies .

Publications:

1. Safiqul Islam, Satadal Datta and Tapas Kumar Das, *A parametric model to study the mass radius relationship of stars*, arXiv:1702.05171 v1 [astro-ph.SR] dt 16.02.17. (It is under review)

2. Safiqul Islam, Priti Mishra and Farook Rahaman, *A Reissner-Nordström $+\Lambda$ black hole in the Friedman-Robertson-Walker universe*, arXiv:1703. 05119v1 [phys.gen.ph] dt 5.03.17. (It is under review)

3. Safiqul Islam and Iftikar H. Sardar, *Model of a charged isotropic star in $f(R,T)$ gravity embedded in an exterior Schwarzschildt metric*, [The paper is in progress]

4. Safiqul Islam, Md Arif Shaikh and Tapas Kumar Das, *Comparative study of wormholes with charge under some density profiles of galaxies*, [The paper is in progress]

Conference/Workshops Attended:

1. *29th meeting of the Indian Association for General Relativity and Gravitation (IAGRG)*, IIT Guwahati, Assam, India, 18-20 May, 2017.
(Presented a paper titled "A Reissner-Nordström$+\Lambda$ black hole in the Friedman-Robertson-Walker universe").

2. *35th Meeting of the Astronomical Society of India (ASI)* , Jaipur, India, 6-10 March, 2017.
(Presented a paper titled "Wormholes supported by two non-interacting fluids").

3. *CIMPA-INDIA research school*, Jadavpur University, Kolkata, India, December 1-12, 2016 (Participated).

Visits to other Institutes:

1. Department of Physics, University of Lucknow, Lucknow, India, September 21-22, 2016.

Invited Lectures/Seminars:

1. *Cosmological models of the universe and Wormholes supported by two non-interacting fluids*, Wormholes, Department of Mathematics, RTM Nagpur University, Nagpur, January 14-24, 2017.

2. National Seminar on Differential Equations and Lie Groups , Bangabasi Evening College, Kolkata, November 10-12, 2016 (Invited Participation).

Academic recognition/Awards:

- Visiting Fellow, Department of Mathematics, RTM Nagpur University, Nagpur, January 14-24, 2017.

Other Activities:

1. Revieweer, International Journal of Astrophysics and Space Science (IJASS), April 20, 2017.

2. Revieweer, Boletim Sociedade Paranaense de Matematica, March, 2017.

3. Life Member, Indian Mathematical Society, September 15, 2016.

Dushyant Kumar

Research Summary:

We have introduced a framework for non-linear time evolution in quantum mechanics and, within this framework, have derived simple toy models of gravity on finite graphs. Along similar lines we have also proposed a model of non-linear quantum field theory on spaces with state-dependent geometry.

The basic idea for our model for non-linear time evolution comes from Random Matrix theory (RMT). In RMT one studies statistical spectral properties of an ensemble of Hamiltonians. We extend this idea into dynamical regime and propose time evolution under a fixed ensemble of Hamiltonians where the probability distribution of Hamiltonians is state-dependent. More precisely the idea is following. Instead of a single Hamiltonian consider an ensemble of Hamiltonians $\{H_1(\vec{l_1}), \ldots, H_k(\vec{l_k}), \ldots\}$. When the system is in state $|\psi\rangle$, the probability associated with H_i is taken to be of the form $\frac{1}{Z}\exp(-\beta\langle\psi|H_i|\psi\rangle - \alpha f(H_i;\vec{l_i}))$ where, $f(H_i;\vec{l_i})$ is a scalar valued function of H_i, and (or) the parameters $\vec{l_i}$ appearing in H_i, α and β are some dimensionful constants, and

$$Z = \sum_i \exp\left(-\beta\langle\psi|H_i|\psi\rangle - \alpha f(H_i;\vec{l_i})\right)$$

Time evolution (of a normalized state) is now defined to be under the average Hamiltonian of the given ensemble. That is,

$$i\frac{d|\psi\rangle}{dt} = H_{avg}|\psi\rangle$$

where,

$$H_{avg} = \frac{1}{Z}\sum_i H_i \exp\left(-\beta\langle\psi|H_i|\psi\rangle - \alpha f(H_i;\vec{l_i})\right)$$

The formalism comes naturally equipped with its own thermodynamics where the thermodynamic quantities are defined by taking Z as the partition function. In particular, one can define an energy functional

$$\begin{aligned} U = \langle\psi|H_{avg}|\psi\rangle &= \frac{1}{Z}\sum_i \langle\psi|H_i|\psi\rangle \exp\left(-\beta\langle\psi|H_i|\psi\rangle - \alpha f(H_i;\vec{l_i})\right) \\ &= -\frac{\partial}{\partial\beta}\bigg|_r \log(Z) \end{aligned}$$

and the entropy functional

$$S = -\left(\beta\frac{\partial}{\partial\beta} + \alpha\frac{\partial}{\partial\alpha} - 1\right)\bigg|_r \log(Z)$$

where, $\big|_r$ in these expressions denote restricted partial derivatives which neglect the dependence of state $|\psi\rangle$ on α and β.

Consider a geometric graph with N vertices numbered as $i = 1, \ldots, N$ and with weights $a_{ij} = a_{ji}$ associated with edges, where, $a_{ij} = 0$ if i, j are not neighbouring vertices or $i = j$. Considering the case of a scalar field theory, we attach quantum degrees of freedom $\hat{\pi}_i, \hat{\phi}_i$ to each vertex i. Now, we consider the ensemble of all scalar field Hamiltonians for all different graph geometries on the graph of a fixed topology. These Hamiltonians are the form

$$H = \frac{1}{2}\sum_{j=1}^{N}\hat{\pi}_j^2 + \frac{1}{2}\sum_{<ij>} a_{ij}(\hat{\phi}_i - \hat{\phi}_j)^2 + \frac{1}{2}m^2\sum_{i=1}^{N}\phi_i^2 + \frac{\lambda}{n!}\sum_{i=1}^{N}\phi_i^n$$

We take our probability function in a state $|\psi\rangle$ to be $P(H) = \beta\langle\psi|H|\psi\rangle - \frac{\alpha}{2}\mathrm{Tr}(\nabla^2)$. The integration measure is

$$d\mu = \prod_{<ij>} da_{ij}$$

where the domain of integration for each edge weight is $(0, \infty)$. The average Hamiltonian is easily computed and comes out to be

$$H_{avg} = \frac{1}{2}\sum_{j=1}^{N}\hat{\pi}_j^2 + \frac{1}{2}\sum_{<ij>} l_{ij}(\hat{\phi}_i - \hat{\phi}_j)^2 + \frac{1}{2}m^2\sum_{i=1}^{N}\phi_i^2 + \frac{\lambda}{n!}\sum_{i=1}^{N}\phi_i^n$$

where, for neighbouring i, j

$$l_{ij} = \frac{1}{\frac{\beta}{2}\langle\psi|(\hat{\phi}_i - \hat{\phi}_j)^2|\psi\rangle + \alpha}$$

The only effect of the ensemble averaging is to make the geometry of the graph state-dependent. The Hamiltonian is highly non-linear but its possible to compute the vacuum solution under some special conditions. For example, the vacuum state of a free theory on graphs with discrete translation invariance can be found in following steps.

- Find the vacuum state of the linear theory on the graph where each edge is assigned a fixed weight a^2. Lets call this vacuum state to be $|0, a^2\rangle$.
- Compute the value $l_{ij} = \frac{1}{\frac{\beta}{2}\langle 0, a^2|(\hat{\phi}_i - \hat{\phi}_j)^2|0, a^2\rangle + \alpha}$ for any fixed neighbouring sites i, j. The result will be independent of the choice of i and j due to translational invariance. Call the function so obtained as $g(a^2, \beta, \alpha)$.
- Solve the equation $g(a^2, \beta, \alpha) = a^2$ for a in terms of α and β. Let the solution be a_0.
- Then the required vacuum state will be $|0, a_0^2\rangle$.

Time evolution of the vacuum state is governed by the linear Schrodinger equation. Therefore, any state which deviates only a little from the vacuum state is expected to follow linear time evolution.

Its difficult to apply our formalism of non-linear time evolution to continuum spaces simply because the moduli spaces of metrics in the continuum are infinite dimensional and integration over them is highly non-trivial. However, one can try to formulate models of non-linear QFT on continuum spaces in analogy with the toy model of non-linear QFT on graphs. The only condition we impose on such models is that the geometry be state-dependent and reduce to flat geometry, with linear time evolution for the vacuum state. The most important information one needs for defining a field theory on a state-dependent geometry is an expression for the metric in terms of expectation value of a local operator. The geometry in case of a finite graph depends on the state through the expectation value $\langle\psi|(\hat{\phi}_i - \hat{\phi}_j)^2|\psi\rangle$. In the continuum limit this quantity would be similar to $\langle\psi|\left(\partial_x\hat{\phi}(x)\right)^2|\psi\rangle \sim \lim_{x\to y}\partial_x\partial_y\langle\psi|\hat{\phi}(x)\hat{\phi}(y)|\psi\rangle$. Therefore, we expect that the metric in case of continuum spaces should somehow be recoverable from the singular limit of double derivatives of the Green's function. Such an expression for the the metric in terms of Green's function has already been derived by Mehdi, Siavash and Achim in PRD **93** (2016) 045026

$$g_{ij}(x) \sim \lim_{x\to y}\frac{\partial}{\partial x^i}\frac{\partial}{\partial y^j}\left(G(x,y)^{\frac{2}{2-D}}\right)$$

Here D is the dimension of spacetime which is required to be ≥ 3. Using this result of Mehdi, Siavash and Achim one can define a non-linear scalar field theory on a space of the form $\mathbb{R}^d\times\mathbb{R}$ with a state-dependent metric of the form $dt\otimes dt + h_{ij}(x,t)dx^i\otimes dx^j$ as follows. First we choose a spatial slice $\mathbb{R}^d\times\{t_0\}$ and attach quantum degrees of freedom $\hat{\pi}(t_0,\vec{x}), \hat{\phi}(t_0,\vec{x})$ to each point $(t_0,\vec{x})$ of this slice. These degrees of freedom are required to satisfy commutation relation $[\hat{\phi}(\vec{x}),\hat{\pi}(\vec{y})] = i\delta^d(\vec{x}-\vec{y})$ where $\delta^d(\vec{x}-\vec{y})$ is the delta function on $\mathbb{R}^d\times\{t_0\}$ with respect to a flat metric. Define the state-dependent metric on the spatial slice as

$$h_{ij}(\vec{x}) \sim \lim_{\vec{x}\to\vec{y}}\frac{\partial}{\partial x^i}\frac{\partial}{\partial y^j}\left(\langle\psi|\hat{\phi}(\vec{x})\hat{\phi}(\vec{y})|\psi\rangle^{\frac{2}{1-d}}\right)$$

Use this state-dependent metric to define the Hamiltonian for the non-linear scalar field theory as

$$H = \frac{1}{2}\int d^dx\left(\frac{\hat{\pi}^2(\vec{x})}{\sqrt{h}} + \sqrt{h}\,h^{ij}\partial_i\hat{\phi}\,\partial_j\hat{\phi} + m^2\sqrt{h}\,\hat{\phi}^2\right)$$

This non-linear theory has some level of similarity with the theory on finite graphs. The vacuum state is simply the flat space vacuum of the scalar field. Also, the theory would reduce to a linear theory if the initial state is vacuum state, and hence, can be expected to be "close to linear" for any state "close to vacuum". However, in contrast to the theory on finite graphs, we are not yet sure if this theory can somehow be derived within our formalism.

Publications:

1. Dushyant Kumar and Menika Sharma, *Conformal embeddings and higher-spin bulk duals*, Phys. Rev. D **95**, 066015, (2017).

Preprints:

1. Dushyant Kumar, *Nonlinear Time Evolution and Field Theories on State-Dependent Geometries* (in preparation).

Conference/Workshops Attended:

1. *School and Workshop on Modular Forms and Black Holes*, NISER Bhubaneswar, India, January, 2017.

2. *Indian String Meeting*, IISER Pune, India, December, 2016.

3. *HRI Workshop on String Theory: Developments in String Perturbation Theory*, HRI Allahabad, India, February 2016.

Other Activities:

1. Gave two lectures on "Physics with Visual Python" in Rajbhasha Scientific Workshop held in HRI, Allahabad during 15th-19th May, 2017.

Tanmoy Mondal

Research Summary:

Super-symmetry is one of the most theoretically motivated new physics scenario and generic SUSY search has explored vast region of parameter space and pushed the SUSY scale at very high value. However, there exist few blind spots in the parameter space which are of special interest since the conventional channels have limitation and thus excluded limits are significantly weak for those region. The blind spots involving top squark are of utmost importance as the top squark helps in stabilizing the Higgs boson mass against large quantum correction. Lots of focus, both phenomenologically and experimentally, poured in to exploring one such difficult region with top squark, where mass range is nearly degenerate to the lightest SUSY particle. We investigate the usefulness of different kinematic variables sensitive to the compressed mass region, and propose a search strategy considering phenomenological supersymmetric scenario where the top squark undergoes a four-body decay due to its extremely narrow mass difference with the lightest supersymmetric particle. Considering a challenging but relatively clean decay channel, we demonstrate that one can effectively restrain the significant background from top which consequently improve the present exclusion limit with 13 TeV data.

Preprints:

1. Partha Konar, Tanmoy Mondal and Abhaya Kumar Swain , *Demystifying compressed top squark region with kinematic variables*, arXiv:1612.03269.

Conference/Workshops Attended:

1. *XXII DAE-BRNS High Energy Physics Symposium 2016*, India, December, 2016.

Visits to other Institutes:

1. Physical Research Laboratory, Ahmedabad, India, March, 2017.

Priti Mishra

Research Summary:

Curious case of gravitational lensing by binary black holes: a tale of two photon spheres, new relativistic images and caustics: Binary black holes have been in limelight off late due to the detection of a gravitational waves from coalescing compact binaries in the events GW150914 and GW151226. In this paper we study gravitational lensing by the binary black holes modelled as an equal mass Majumdar-Papapetrou di-hole metric and show that this system displays features that are quite unprecedented and absent in any other lensing configuration investigated so far in the literature. We restrict our attention to the light rays which move on the plane midway between the two identical black holes, which allows us to employ various techniques developed for the equatorial lensing in the spherically symmetric spacetimes. If distance between the two black holes is below a certain threshold value, then the system admits two photon spheres. As in the case of single black hole, infinitely many relativistic images are formed due to the light rays which turn back from the region outside the outer (unstable) photon sphere, all of which lie beyond a critical angular radius with respect to the lens. However in the presence of the inner (stable) photon sphere, the effective potential after admitting minimum turns upwards and blows up for the smaller values of radii and the light rays that enter the outer photon sphere can turn back, leading to the formation of a new set of infinitely many relativistic images, all of which lie below the critical radius from the lens mentioned above. As the distance between the two black hole is increased, two photon spheres approach one another, merge and eventually disappear. In the absence of the photon sphere, apart from the formation of a finite number of discrete relativistic images, the system remarkably admits a radial caustic, which has never been observed in the context of relativistic lensing before. Thus the system of binary black hole admits novel features both in the presence and absence of photon spheres. We discuss possible observational signatures and implications of the binary black hole lensing.

Redshift and redshift-drift in $\Lambda = 0$ quasi-spherical Szekeres cosmological models and the effect of averaging: Since the advent of the accelerated expanding homogeneous universe model, some other explanations for the supernova Ia dimming have been explored, among which there are inhomogeneous models constructed with exact $\Lambda = 0$ solutions of Einstein's equations. They have been used either as one patch or to build Swiss-cheese models. The most studied ones have been the Lemaître-Tolman-Bondi (LTB) models. However, these models being spatially spherical, they are not well designed to reproduce the large scale structures which exhibit clusters, filaments and non spherical voids. This is the reason why Szekeres models, which are devoid of any symmetry, have recently come into play. In this paper, we give the equations and an algorithm to compute the redshift-drift for the most general quasi-spherical Szekeres (QSS) models with no dark energy. We apply it to a QSS model recently proposed by Bolejko and Sussman (BSQSS model) who averaged their model to reproduce the density distribution of the Alexander and collaborators' LTB model which is able to fit a large set of cosmological data without dark energy. They concluded that their model represents a significant improvement over the observed cosmic structure description by spherical LTB models. We show here that this QSS model is ruled out by a negative cosmological redshift, i.e. a blueshift, which is not observed in the Universe. We also compute a positive redshift and the redshift-drift for the Alexander et al.'s model and compare this redshift-drift to that of the ΛCDM model. We conclude that the process of averaging an unphysical QSS model can lead to obtain a physical model able to reproduce our observed local Universe with no dark energy need and that the redshift-drift can discriminate between this model and the ΛCDM model. For completeness, we also compute the blueshift-drift of the BSQSS model.

A Reissner-Nordström+Λ black hole in the Friedman-Robertson-Walker universe: A charged, non-rotating, spherically symmetric black hole which has cosmological constant Λ (Reissner-Nordström+Λ or RN+Λ), active gravitational mass M and electric charge Q is studied with exterior Friedman-Robertson-Walker (FRW) universe in (2+1) dimensional spacetime. We find a new classes of exact solutions of the charged black hole where the generalized Birkoff's theorem is assumed to be valid. It is found that the cosmological constant is negative inside the black hole. We confirm it from the geodesic equations too. The cosmological constant is found to be dependent on R, Q and $a(v)$ which correspond to the areal radius, charge, of the black hole and the scale factor of the universe respectively. We note that the expansion of the universe affects the size and the mass of the black hole. An important observation is that, for an observer at infinity, both the mass and charge of black hole increase with the contraction of the universe and decrease with the expansion of the universe.

Publications:

1. Mandar Patil, Priti Mishra and D. Narasimha, *Curious case of gravitational lensing by binary black holes: a tale of two photon spheres, new relativistic images and caustics,* Phys. Rev. D **95**, 024026, (2017).

Preprints:

1. Priti Mishra, *Redshift and redshift-drift in $\Lambda = 0$ quasi-spherical Szekeres cosmological models and the effect of averaging,* arXiv:1403.5229

2. Safiqul Islam, Priti Mishra and Farook Rahaman, *A Reissner-Nordström+Λ black hole in the Friedman-Robertson-Walker universe,* arXiv:1703.05119

Conference/Workshops Attended:

1. *35th Meeting of Astronomical Society of India*, Jaipur, India, 6 - 10 March, 2017.

Visits to other Institutes:

1. Inter-University Center for Astronomy and Astrophysics, Pune, India, 2 - 20 February, 2017

Priyanka Mohan

Research Summary:

During the academic year 2016-2017, I with Prof. Sumathi Rao and other collaborators studied the effect of periodic driving in spin-orbit coupled materials. The system we studied consists of a buckled honeycomb tight binding lattice with spin-orbit coupling modeled on silicene, germanene and stanene irradiated by a laser. The phase diagram of this model was studied using a high frequency expansion based on Brillouin-Wigner perturbation theory. Here the frequency of the radiation is much larger than any other energy scale of the system to cause electronic excitations. The incident light thus renormalizes the coupling parameters of the theory to give a time averaged effective Hamiltonian. The phase diagram of the model is constructed by numerically computing the Chern numbers using both the effective Hamiltonian and the Floquet Hamiltonian to check the validity of the expansion. It is found that the results from both the methods matches very well at high frequencies. In addition to this, we are looking into the effects of periodic driving in bilayer graphene and silicene. These are studied both analytically using high frequency expansion techniques and numerically exact calculations.

Publications:

1. Priyanka Mohan, Ruchi Saxena, Arijit Kundu and Sumathi Rao, *Brillouin-Wigner Theory for Floquet Topological Phase Transitions in Spin-orbit Coupled Materials, Phys. Rev. B* 94, 235419 (2016).

Conference/Workshops Attended:

1. School on Current Frontiers in Condensed Matter Research, ICTS Bangalore, 20-29 June 2016.

2. Discussion Meeting on Nonequilibrium Quantum Many Body Physics, HRI Allahabad, 21-25 November 2016.

3. Workshop on Probes for Exotic States of Matter, MPIPKS Dresden, Germany, 27-30 March 2017.
   Poster presentation:"*Photo-induced topological transitions in spin-orbit coupled materials* - Priyanka Mohan, Ruchi Saxena, Arijit Kundu and Sumathi Rao. "

Visits to other Institutes:

1. IACS Kolkatta, India August 2016.

2. Dept of Physics, Karlsruhe institute of Technology, Karlsruhe, Germany, March 2017.

3. Max-Planck institute for Physics of complex System, March 2017.

Keita Nii

Research Summary:

I have studied two different topics this year. I first investigated dynamics of three-dimensional supersymmetric gauge theories. The 3d gauge theories are strongly-coupled systems and it's difficult to study them by the usual perturbation method. But for those theories, we can construct the dual description which is in the same universality class as the original theory we want to study and this dual theory is weakly coupled. So it is easy to study the dynamics of the dual theory. This dual description is called " Seiberg duality". Recently the construction of the Seiberg duality in 3d was deeply developed. However if the theory contains various matter fields, there was no known dual description for it. I constructed the general method of constructing the 3d duality for theories with various matter fields. It is called "3d deconfinement method" (Reference: Publication list [2]). Next I have studied conformal field theories (CFTs) (Publication list [1]). Especially I focused on the Wilson-Fisher CFTs which describe the phase transition of the Ising model. Then it is important to study the critical exponents for these theories. In this paper [1], I have shown that the leading corrections for these exponents can be calculated by using only the conformal properties and the classical equations of motion. Usually these quantities are calculated by the usual perturbation method which is messy. Our method is more simple and elementary.

Publications:

1. Keita Nii *Classical equation of motion and Anomalous dimensions at leading order,* Journal of High Energy Physics **1607**, 107 (2016).

2. Keita Nii, *3d Deconfinement, Product gauge group, Seiberg-Witten and New 3d dualities,* Journal of High Energy Physics **1608**, 123, (2016).

Preprints:

1. Keita Nii *Classical equation of motion and Anomalous dimensions at leading order,* arXiv:1605.08868 [hep-th]

2. Keita Nii, *3d Deconfinement, Product gauge group, Seiberg-Witten and New 3d dualities,* arXiv:1603.08550 [hep-th]

Conference/Workshops Attended:

1. *Indian Strings Meeting 2016*, India, December, 2016

2. *Strings 2016*, China, August, 2016.

Invited Lectures/Seminars:

1. *3d deconfinement method and S-confining gauge theories*, a talk given in Indian Strings Meeting 2016, IISER Pune, India, December, 2016.

Abhishake Sadhukhan

Research Summary:

The dressing method is a technique to generate solutions from a given seed solution for 2 d integrable sigma models. The string theory on $AdS_3 \times S^3 \times T_4$ is an integrable sigma model and hence the dressing technique can be applied to generate new solutions. Motivated by this, we take a seed AdS vacuum solution and dress it appropriately to obtain the giant magnon solution in the mixed flux background.

We start the string sigma model action in the mixed flux background which is equivalent to a principal chiral model with a Wess-Zumino term with a coeeficient q.

$$S = -\frac{h}{2}\Big[\int d^2\sigma \frac{1}{2}\mathrm{tr}(\mathfrak{J}_+\mathfrak{J}_-) - q\int d^3\sigma\, \tfrac{1}{3}\varepsilon^{abc}\mathrm{tr}(\mathfrak{J}_a\mathfrak{J}_b\mathfrak{J}_c)\Big]\,,$$

where $\mathfrak{J}_a = g^{-1}\partial_a g$ are the currents. $g \in SU(2)$ and $\sigma^{\pm} = \frac{1}{2}(\tau \pm \sigma)$, $\partial_\pm = \partial_\tau \pm \partial_\sigma$. The equations of motion

$$\partial_\pm \tilde{\mathfrak{J}}_\mp \pm \frac{1}{2}[\tilde{\mathfrak{J}}_+, \tilde{\mathfrak{J}}_-] = 0, \qquad \tilde{\mathfrak{J}}_\pm = (1 \pm q)\mathfrak{J}_\pm$$

can be rephrased as the compatibility condition of the Lax pair equations

$$\partial_\pm \Psi(\sigma^+, \sigma^-; \lambda) = \Psi(\sigma^+, \sigma^-; \lambda)A_\pm \qquad [1]$$

where λ is the spectral parameter and

$$A_\pm = \frac{1}{1 \pm \lambda}\tilde{\mathfrak{J}}_\pm = \frac{1 \pm q}{1 \pm \lambda}\mathfrak{J}_\pm.$$

We shall also impose unitarity

$$\Psi^\dagger(\bar{\lambda})\Psi(\lambda) = 1.$$

Starting with a given solution Ψ we can perform a λ-dependent gauge transformation to obtain a new solution

$$\Psi \& \to \Psi' = \Psi\chi A_\pm \& \to A'_\pm = \chi^{-1}A_\pm\chi + \chi^{-1}\partial_\pm\chi . \& \mathfrak{J}'_\pm = \chi^{-1}\mathfrak{J}_\pm\chi + \frac{1 \pm \lambda}{1 \pm q}\chi^{-1}\partial_\pm\chi$$

If we ensure that $\mathfrak{J}'_\pm$ are independent of λ, then it is guaranteed that $\Psi'(l = 0)$ is a possible new solution to the set of equations([1]). For this to happen, we fix χ to be of the form

$$\chi = 1 + \frac{\lambda_1 - \bar{\lambda}_1}{\lambda - \lambda_1}P$$

where P is a projection operator, i.e. $P = P^2 = P^\dagger$.

The projection operator P is chosen to be

$$P = \frac{\Psi^{-1}(\lambda_1)ee^\dagger\Psi(\bar{\lambda}_1)}{e^\dagger\Psi(\bar{\lambda}_1)\Psi^{-1}(\lambda_1)e}.$$

where e is a constant vector and λ_1 is an arbitrary complex constant. The resulting dressing factor χ has the determinant

$$\det\chi = \frac{\lambda - \bar{\lambda}_1}{\lambda - \lambda_1}$$

and the new dressed solution is given by

$$g_{\text{dressed}} = \sqrt{\frac{\lambda_1 - q}{\bar{\lambda}_1 - q}}\Psi(q)\chi(q)$$

where the normalisation factor ensures that $g \in SU(2)$.

The string equations of motion, in conformal gauge, are equivalent to those of the SU(2) principal chiral model, via the embedding

$$g = \begin{pmatrix} Z_1 \& Z_2 \\ -Z_2^* \& Z_1^* \end{pmatrix} \in SU(2), \qquad |Z_1|^2 + |Z_2|^2 = 1$$

Z_1 and Z_2 can be expressed in terms of global S^3 coordinates as follows

$$Z_1 = \sin\theta e^{i\phi_1}, \qquad Z_2 = \cos\theta e^{i\phi 2}$$

Our aim is to derive the $q \neq 0$ giant magnon solution by dressing up the BMN solution

$$Z_1 = e^{it}, \qquad Z_2 = 0.$$

The dispersion relation is $E = J$ for this solution.

Using the dressing method described above, we find the new solutions to be

$$Z_1 = e^{it}(\cos\frac{p}{2} + i\sin\frac{p}{2}\tanh u), \qquad Z_2 = \sin\frac{p}{2}e^{i(v-qx)}\operatorname{sech} u.$$

where u, v are the functions of worldsheet coordintes t and x. The constant p is introduced because of the arbitrary complex constant λ_1 that was introduced in the dressing method.

The global coordinates θ, ϕ_1, ϕ_2 can be read off from the above solution and the dispersion relation can be computed

$$E - J_1 = \sqrt{(J_2 - hqp)^2 + 4h^2(1-q^2)\frac{\sin^2 p}{2}}$$

Thus we have reproduced the dyonic magnon solution and its dispersion relation using the dressing method.

Conference/Workshops Attended:

1. *Indian Strings Meeting*, IISER Pune, India, December 2016.

Visits to other Institutes:

1. IISER, Pune, December, 2016

Sk Sazim

Research Summary:

Using the variance based uncertainty, we introduce a new concept called as the mutual uncertainty between two observables in a given quantum state which enjoys similar features like the mutual information for two random variables. Further, we define the conditional uncertainty and show that conditioning on more observable reduces the uncertainty. Given three observables, we prove a 'strong sub-additivity' theorem for the conditional uncertainty under certain condition. As an application, we show that for pure product two-qubit states, the mutual uncertainty is bounded by 0.586 and if it is greater than this value then it indicates that the state is entangled. For mixed two-qubit states, we prove that the mutual uncertainty for product, classical-classical, and classical-quantum state also takes a universal value 0.586. We also show how to detect quantum steering using the mutual uncertainty between two observables. Our results may open up a new direction of exploration in quantum theory and quantum information using the mutual uncertainty, conditional uncertainty and the strong sub-additivity for multiple observables.

Preprints:

1. Sk Sazim, Satyabrata Adhikari, Arun K. Pati, and Pankaj Agrawal, *Mutual Uncertainty, Conditional Uncertainty and Strong Sub-Additivity,* arXiv:1702.07576.

Conference/Workshops Attended:

1. *Young Quantum-2017*, India, February, 2017.

Visits to other Institutes:

1. Institute Of Physics, Bhubaneswar, India, November, 2016.

Invited Lectures/Seminars:

1. *Mutual uncertainty, conditional uncertainty and ...*, Young Quantum 2017, Harish-Chandra Research Institute, Allahabad, February, 2017.

Other Activities:

1. Had been a part of local organizing members of the conference: Young Quantum 2017, February, 2017.

Satyananda Singh Chabungbam

Research Summary:

As a part of computational material discovery, we establish the unknown compound $CrCTe_3$ to be a stable anti-ferromagnetic semiconductor using density functional theory in the R-3 crystal structure with an indirect fundamental gap . Successive layers in the bulk compound are weakly bound by Van der Waals forces so that individual layers can be easily exfoliated. Monolayer $CrCTe_3$ is also an anti-ferromagnetic indirect-gap semiconductor. It is structurally stable between 4% compressive and 16% tensile biaxial strain, and the anti-ferromagnetic state is robust over this strain range. Band gap of the monolayer can be tuned by as much as 50% by applied strain in this range. Effects of electric field in similar layered materials are also being explored.

Preprints:

1. Satyananda Chabungbam and Prasenjit Sen, *Computational design of a robust two-dimensional anti-ferromagnetic semiconductor,* under communication

Conference/Workshops Attended:

1. *Asian Consortium on Computational Materials Science (ACCMS)*, 22 to 24th September, 2016, SRM University, Chennai Oral presentation: Phase stability, magnetism and transition temperatures in Ni-Fe-Ga alloys

Dheeraj Kumar Singh

Research Summary:

We have presented a two-orbital tight-binding model with bases belonging to the Γ_8 quartet. The model captures several characteristics of the Fermiology unravelled by the recent angle-resolved photoemission spectroscopic (ARPES) measurements on cerium hexaboride CeB_6. Further, we have calculated various multipolar susceptibilities within the model and identify the susceptibility that shows the strongest divergence in the presence of standard onsite Coulomb interactions and discuss it's possible implication and relevance with regard to the signature of strong ferromagnetic correlations existent in various phases as shown by the recent experiments.

In a separate work, we have investigated the role of Hund's coupling in the spin-wave excitations of the $(\pi, 0)$ ordered magnetic state within a five-orbital tight-binding model for iron pnictides. We find that the Hund's coupling is crucial for the description of various experimentally observed characteristics of the spin-wave excitations including the anisotropy, energy-dependent behavior, and spin-wave spectral weight distribution. Further, we also examined the doping dependence of spin-wave excitations in the spin-density wave (SDW) state of doped iron pnictides

In another work, we have studied the impurity scattering induced quasiparticle interference in the $(\pi, 0)$ SDW of the iron pnictides. Our mean field theory in the clean limit captures key features of the Fermi surface observed in angle-resolved photoemission. Using a t-matrix formalism to incorporate the effect of doping induced impurities on this state it is shown that a spatial modulation of the local density of states about the impurity site, with a periodicity of $\sim 8a_{Fe-Fe}$ along the antiferromagnetic direction which is consistent with spectroscopic imaging scanning tunneling microscopy. Roles of gap characteristics such as anisotropy and inequality of the gaps in the quasiparticle interferences of superconducting (SC) iron pnictides is also investigated. Moreover, quasiparticle interference in the coexistence phase SDW+SC of iron pnictides is also investigated.

Preprints:

1. Dheeraj Kumar Singh, Two-orbital model for CeB6 arXiv:1702.06717

2. Dheeraj Kumar Singh, Spin-wave excitations in the SDW state of iron pnictides: a comparison between the roles of interaction parameters arXiv:1703.03228

3. Dheeraj Kumar Singh, Spin-wave excitations in the SDW state of doped iron pnictides arXiv:1703.06601

4. Dheeraj Kumar Singh, Roles of anisotropic and unequal gaps in the quasiparticle interference of superconducting iron pnictides arXiv:1704.04069

5. Dheeraj Kumar Singh and Pinaki Majumdar, Highly anisotropic quasiparticle interference patterns in the spin-density wave state of the iron pnictides arXiv:1704.04783

6. Dheeraj Kumar Singh, Quasiparticle interferences in the coexistence phase of iron pnictides based on a five-orbital model (in preparation)
7. Dheeraj Kumar Singh and Pinaki Majumdar Conductivity anisotropy in the doped iron pnictides: a consequence of orbital weight redistribution along the reconstructed Fermi surfaces write (in preparation)

Sorokhaibam Nilakash Singh

Research Summary:

I joined HRI on October 3, 2016 as a post doctorate. Before coming to HRI, while in TIFR, in September 2016, I completed a project/work on time evolution of entanglement entropy in dynamical systems. Since joining HRI, I have been working on black hole formation and thermalization of one-point and two-point functions in Conformal Field theories(CFTs) using AdS/CFT techniques. AdS/CFT is a duality matching two systems, one is a strongly interacting CFT(say in d dimensions) which is mapped to the other system, also called bulk which is gravity in AdS space of dimensions higher than d.

Thermalization is the process in which a system in an excited state evolves in time and starts *looking* like a system in a thermal ensemble. Clearly, not every system in an excited state thermalizes. It is widely believed that strongly intereacting CFTs with bulk dual generally thermalize. There is a lot of confusion in literature about thermalization of local operators in these strongly interacting CFTs. Some claim that local operators thermalize instanteneously while others claim that the expectation values of these local operators approaches the thermal values with rates dictated by their lowest quasinormal modes. We wish to clarify this confusion. Moreover, most of the literature deals with only scalar fields. So, we also wish to see how chiral one-point and two-point functions thermalize by examining evolutions of guage field coupled to gravity.

Besides the above work, I am also trying to finish a work which I started in TIFR on BCS theory of Superconductors with my PhD supervisor Prof. Gautam Mandal and Prof. Rajdeep Sensarma. We examine why BCS theory which is a mean field theory is very effective although in more general systems quantum fluctuations would wipe out the order parameter.

Conference/Workshops Attended:

1. *Indian Strings Meeting* held at IISER Pune, India in December 2016.

HRI Colloquia

1. Bikash Chakrabarti: Econophysics of income and wealth inequalities.
2. Neelima Gupte: The simplical characterisation of time series networks: theory and applications.
3. G. Baskaran: Bismuth, a fascinating semimetal.
4. Manoj Harbola: Density functional theory: fundamentals and applications.
5. Bruce Mellado: Understanding the origin of mass at the Large Hadron Collider.
6. Sudip Chakraborty: Development and application of new computational techniques in materials modeling.

Mathematics Talks and Seminars

1. Roman Mikhailov: fr-theory and related questions.
2. Shreedevi Masuti: Hilbert functions of graded and local algebras.
3. Yves Martin: On an integral kernel for twisted Koecher-Maass series associated to Siegel cusp forms of degree two.
4. V.Kumar Murty: On the polynomials $x^n + x + a$;Fourier coefficients of CM modular forms;A variant of Lehmer's conjecture.
5. Keshav Aggarwal: Subconvexity problem and shifted convolution sums.
6. Prabhat Kumar Kushwaha: Use of implicit representation in the discrete logarithm problem and the Diffie-Hellman problem.
7. Anupam Kumar Singh: Gaussian elimination in classical groups.
8. Dinesh Thakur: A tale of two congruences.
9. Ashish K.Srivastava: An introduction to cluster algebras.
10. Pedro A.Guil Asensia: Approximation Theory in Exact Categories and Phantom maps.
11. Sergie Ivanov: Group theory and homotopy groups of spheres. Wu's formula; HR-localization and HR-length of groups;Higher limits, homology theories and (f,r) codes.
12. Vladimir Sosnilo: Non-commutative localizations of rings and additive categories.
13. Danila Cherkashin: Hypergraph Colourings.
14. Jean-Marc Deshouillers: Integral points on a convex curve (joint work with Georges Grekos and Adrian Ubis Martinez).
15. Robert Wisbauer: Introduction to coalgebras.
16. Silvio Dolfi: Coprime subdegrees of primitive permutation groups.

Mathematics Colloquia

1. I.B.S. Passi: Group Rings.

2. S.Thangavelu: Hardy type inequalities for fractional powersof the sublaplacian on the Heisenberg group.

3. Factoring Polynomials and Abelian Varieties.

Physics Talks and Seminars

1. Amitava Virmani: Inter structure of charged AdS Black Holes.
2. Seema Satin: Noise kernel for self similar Tolman-Bondi metric: fluctuations at Cauchy horizons.
3. Abhishek K.Singh: Challenges and opportunities in designing efficient thermoelectric materials.
4. Debangshu Mukherjee: Hyperscaling violation and the shear diffusion constant.
5. Tuhin S.Roy: QJets.
6. Partha Konar: Demystifying compressed top squark region with kinematic variables.
7. Ritesh K.Singh: Playing with spin quantum numbers at colliders.
8. Moitri Maity: Dynamical responses of unconventional Josephson junctions.
9. Bruce Mellado: New scalar bosons and the production of multiple leptons at the LHC; non-standard resonance searches at the LHC.
10. Gauhar Abbas: Spontaneous breakdown of parity in a class of gauge theories.
11. Prarit Agarwal: N=1 Lagrangians and the full superconformal index for Argyres-Douglas theories.
12. Arnab Kundu: Fundamental flavours, Veneziano limit and holography.
13. Sabyasachi Chakraborty: Two places where SUSY can hide.
14. Tanumoy Mondal: Search for heavy neutrinos at LHC.
15. Ritabrata Bhattacharya: Calculation of topological partition function from Superstring amplitudes.
16. Subhroneel Chakrabarti: Using pure spinors to compute mass renormalization in Superstring Theory.
17. Abhishek Joshi: Phase fluctuation theory of Superfluid Mott problem in bose systems.
18. Krishna Mohan Tripathi: Fingerprints of Majorana bound states in Aharonov-Bohm geometry.
19. Juhi Dutta: A revisit to a compressed supersymmetric spectrum with 125 GeV Higgs.
20. Dibya Kanti Mukherjee: Chiral nodes and oscillations in the Josephson current in Weyl semimetals.
21. V Suryanarayana: Neutrino mass correction to Higgs mass in nuMSSM.

22. Aditya Banerjee: Effects of long range Coulomb interaction on triple-Weyl semimetals.

23. Udit Khanna: Edge reconstruction and mode switching in quantum hall states.

24. Ruchi Saxena: Topological Phases in driven 2D Dirac systems with SO-coupling.

25. Anirban Basu: Proving relations between modular graph functions.

26. Sachin Jain: Causality constraint on conformal field theory.

27. Sitender Pratap Kashyap: Construction of integrated form of massive vertex operator in pure spinor formalism.

28. Sunil Mukhi: Recent Developments in 2d Rational Conformal Field Theory.

29. Vlad Vaganov: Big crunch singularities in AdS and relevant deformations of CFT's.

30. Abhishek Sadhukhan: Generating string solutions in the $AdS_3 \times S^3$background with mixed flux.

31. Priyanka Mohan: Shining light on spin orbit coupling: A Brillouin Wigner Approach.

32. Manimala Mitra: Direct and Indirect Searches for Type-II Seesaw and MLRSM.

33. Arijit Dutta: Spin-orbit coupled bosons in a lattice.

34. Victor Mukherjee: Speed limits in quantum heat engines.

35. Pragati Chaturvedi: Topological insulators : growth, characterization and device fabrication.

36. Subhaditya Bhattacharya: Phenomenology of simplest scalar and fermionic dark matter models.

37. Debjyoti Dutta: Imprints of new physics at long baseline neutrino experiments.

38. Jose Wudka: Phenomenology of simplest scalar and fermionic dark matter models.

39. Tirtha Sankar Ray: Extended Folded-SUSY Models: electroweak symmetry breaking and hidden folded-stop.

Physics Colloquia

1. Amitava Moitra: An overview of multiscale modelling to understand material behaviour.
2. Rohini Godbole: Whither colliders: after the LHC?
3. Bidya Binay Karak: Solar magnetic fields and cycles: understanding the dynamo mechanism.
4. Sreerup Raychaudhuri: Electroweak physics - the catastrophe of success.
5. Subinay Dasgupta: Dynamics of quantum spin models out of equilibrium.

Recent Graduates

1. **Akansha Singh**, *First principles studies of substrate supported ′ metal clusters: from fundamentals to applications*.

2. **Divyang Bhimani**, *Modulation Spaces and Nonlinear Evolution Equations*.

3. **Abhishek Chowdhury**, *Finer Consistency Checks on BPS Black Hole Entropy in String*.

4. **Avinanda Chaudhuri**, *Seesaw and seesaw-like scenarios: Some phenomenological implications*.

5. **Swapnamay Mondal**, *Zero Angular Momentum Conjecture for BPS Black Holes in String Theory*.

6. **Mehedi Masud**, *CP Violation and Mass Hierarchy sensivities at long baseline neutrino experiments*.

7. **Utkarsh Misra**, *Dynamics of Quantum Correlations in clean and disordered many-particle systems*.

8. **Sneh Bala Sinha**, *On the transcendence of certain numbers and some identities*.

9. **Pallab Kanti Dey**, *Some problems in elliptic curves and Diophantine Equations*.

10. **Debika Banerjee**, *Some results related to Riesz sum and K-free integers*.

11. **Bibekananda Maji**, *A study of some Lambert Series*.

Publications

Publications (Mathematics)

1. S. D. Adhikari, L. Boza, S. Eliahou, J. Marín, M. Revuelta and M. Sanz, *On the finiteness of some n-color Rado Numbers*, Discrete Math. **340**, 39-45 (2017).
2. S. D. Adhikari, Anirban Mukhopadhyay and M. Ram Murty, *The analog of the Erdős distance problem in finite fields*, Int. J. Number Theory, (to appear).
3. S.Eswara Rao and Punita Batra, *Classification of irreducible integrable highest weight modules for current Kac-Moody algebras,* Journal of Algebra and its Applications, Number 7, Volume 16, (2017).
4. Punita Batra and Hiroyuki Yamane, *Centers of Generalized quantum groups,* To appear in Journal of Pure and Applied Algebra, available online June 9, 2017.
5. S. Eswara Rao and Punita Batra, *On integrable modules for the twisted full toroidal Lie algebra,* To appear in Journal of Lie Theory.
6. Kalyan Chakraborty, Shigeru Kanemitsu and Takako Kuzumaki, *A Quick Introduction To Complex Analysis*, World Scientific, Singapore, (2016).
7. K. Chakraborty, I. Kátai and B. M. Phong, *Additive functions on the greedy and lazy Fibonacci expansions,* J. Integer Seq. **19** Issue 4, 16.4.5, 12 pp. 11B39 (11A25 11A67) (2016).
8. Kalyan Chakraborty, Shigeru Kanemitsu and Bibekananda Maji, *Modular-type relations associated to the Rankin-Selberg L-functions,* The Ramanujan Journal **42**, Issue. 2, 285–299, (Feb. 2017).
9. Kalyan Chakraborty, Jorge Jimenez Urroz and Francesco Pappalardi, *Pairs of integers which are mutually squares,* Sci. China Math., 1–14, (2017) DOI : 10.1007/s.1. 1425-010-0343-1.
10. B. Maji, D. Banerjee, K. Chakraborty and S. Kanemitsu, *Abel-Tauber process and asymptotic formulas,* Kyushu J. of Mathematics, (Accepted for Publication).
11. B. Maji, A. Juyal, K. Chakraborty and S. D. Kumar, *Asymptotic expansion of a Lambert series,* International Journal of Number Theory, (Accepted for Publication).
12. Chandan Singh Dalawat & Jung-Jo Lee, *Tame ramification and group cohomology*, Journal of the Ramanujan Mathematical Society **32**(1), 51–74, 2017.
13. Manoj K. Yadav, *Central quotient versus commutator subgroup of groups,* Algebra and its Applications, Springer Proceedings in Mathematics and Statistics **174**, 183 - 194, (2016).

14. Gyan Prakash, D.S. Ramana and O. Ramaré *Monochromatic Sums of Squares,* accepted in Math. Zeitshrift.

15. J. Cilleruelo, D.S. Ramana and O. Ramaré *Quotient and product sets of thin subsets of the positive integers,* Proceedings of the Steklov Institute of Mathematics, Vol. 296, No. 1, pp. 52-64, 2017.

16. Adimurthi, P.K. Ratnakumar and Vijay Kumar Sohani, *A HardySobolev inequality for the twisted Laplacian,* Proceedings of the Royal Society of Edinburgh Section A: Mathematics **Vol 147**, 1-23, (2017).

17. Hemangi Shah, *3-dimensional asymptotically harmonic manifolds with minimal horospheres,* Arch. Math. **106**, 81-84, (2016).

18. M. N. Chintamani, P. Paul and R. Thangadurai, *On the EGZ constant on finite abelian groups*, To appear in:Integers, 2017.

19. N. K. Meher, K. Senthil Kumar and R. Thangadurai, On a theorem of Mahler, To appear in: Proc. Amer. Math. Soc. (Series A), 2017.

20. Nianliang Wang and Soumyarup Banerjee, *On the product of Hurwitz zeta-functions*, Proc. Jpn. Acad., Ser. A, **93**, 31-36, (2017).

21. Sumana Hatui, *A characterization of finite p-groups by their Schur multiplier,* Accepted for publication in Proc. Indian Acad. Sci. Sect. A Math. Sci (2017).

22. A. Kumar and J. Meher, *On arbitrary products of eigenforms,* Acta Arithmatica **173 (3)**, 283–295, (2016).

23. A. Kumar, *Adjoint of Serre derivative map and special values of shifted Dirichlet series,* J. of Number Theory **177**, 516–527, (2017).

24. Nabin Kumar Meher and Veekesh Kumar, *Subspace lang conjecture and some remarks on a transcendental criterian,* Proc. Indian Acad. Sci. Math. Sci. (To appear).

25. R. Dey and R.K. Singh, *Born-Infeld solitons, maximal surfaces, Ramanujan's identities,* Arch. Math.(Basel) **108-5**, 527–538, (2017)

26. Saibal Ganguli, *On Hodge Structures opf quasitoric orbifold* J. Korean Math. Soc. 2017 **Vol. 54, No. 3, 733-748..**

27. Rukmini Dey, Saibal Ganguli *The Hilbert space of quantization of vortices on a Riemann surface,* To appear International Journal of Geometric methods in Modern Physics

28. H. Kalita, A. Hoque and H. K. Saikia *On ξ-torsion modules,* Boll. Unione Mat. Ital., **10 (2)**, 223-228, (2017).

29. R. D. Kitture, M. K. Yadav, *Note on Caranti's method of construction of Miller groups* Monatshefte fur Mathematik (to appear) (2017) DOI: 10.1007/s00605-016-0976-z.

30. Kumari, Rani; Sarkar, Jaydeb; Sarkar, Srijan; Timotin, Dan, *Factorizations of kernels and reproducing kernel Hilbert spaces*, Integral Equations Operator Theory, **87(2)**, 225– 244, (2017).

31. Raj Kumar Mistri, *Sum of dilates of two sets,* Notes Number Theory Discrete Math. (Accepted).

32. Saudamini Nayak, *Schur multiplier of nilpotent Lie superalgebras,* communicated.

33. Ram Murty and Sudhir Pujahari, *Distinguishing Hecke eigenforms,* Proc. Amer. Math. Soc., 145 (2017), 1899-1904.

34. P.K. Dey and S. S. Rout, *Diophantine equations concerning balancing and Lucas balancing numbers*, Arch. Math. (Basel) **108**(1) (2017), 29–43.

35. S. Chavan, D. Pradhan and S. Trivedi, *Multishifts on Directed Cartesian Product of Rooted Directed Trees,* Dissertationes Mathematicae, *to appear.*

36. Julien Roth and Abhitosh Upadhyay, *Biharmonic submanifolds of Generalized Space Forms,* Differential Geometry and its Applications **50**, 88–104, (2017).

37. Abhitosh Upadhyay and Nurettin Cenk Turgay, *A Classification of Biconservative Hypersurfaces in a Pseudo-Euclidean Space,* J. Math. Anal. Appl. **444**, 1703–1720, (2016).

38. *On the distribution of values of Hardy's Z-function in short intervals* accepted

Publications (Physics)

1. Anirban Basu, *Non–analytic terms from nested divergences in maximal supergravity,* Class.Quant.Grav. **33 no.14**, 145007, (2016).

2. Anirban Basu, *Poisson equation for the three loop ladder diagram in string theory at genus one,* Int.J.Mod.Phys. A **31 no.32**, 1650169, (2016).

3. Anirban Basu, *Proving relations between modular graph functions,* Class.Quant.Grav. **33 no.23**, 235011, (2016).

4. Sandhya Choubey, *Atmospheric Neutrinos: Status and Prospects,* Nucl. Phys. **B908**, 235 (2016).

5. Sandhya Choubey, Dipyaman Pramanik, *Constraints on Sterile Neutrino Oscillations using DUNE Near Detector,* Phys. Lett. **B764**, 135, (2016).

6. Anirban Biswas, Sandhya Choubey, Sarif Khan, *Galactic gamma ray excess and dark matter phenomenology in a* $U(1)_{B-L}$ *model,* JHEP **1608**, 114, (2016).

7. Shiba Prasad Behera, Anushree Ghosh, Sandhya Choubey, V.M. Datar, D.K. Mishra, A.K. Mohanty, *Search for the sterile neutrino mixing with the ICAL detector at INO,* Eur. Phys. J. **C77**, 5, (2017).

8. Mattias Blennow, Sandhya Choubey, Tommy Ohlsson, Dipyaman Pramanik, Sushant K. Raut *A combined study of source, detector and matter non-standard neutrino interactions at DUNE,* JHEP **1608**, 090, (2016).

9. Anirban Biswas, Sandhya Choubey, Sarif Khan, *Neutrino Mass, Dark Matter and Anomalous Magnetic Moment of Muon in a* $U(1)_{L_\mu - L_\tau}$ *Model,* JHEP **1609**, 147, (2016).

10. Anirban Biswas, Sandhya Choubey, Sarif Khan, *FIMP and Muon* $(g-2)$ *in a* $U(1)_{L_\mu - L_\tau}$ *Model,* JHEP **1702**, 123, (2017).

11. Arif Shaikh, Md., Firdousi, Ivleena., & Das, Tapas K., *Relativistic sonic geometry for isothermal accretion in the Schwarzschild metric*, Classical and Quantum Gravity **34**, Issue 15, article id. 155008 (2017).

12. Bollimpalli, Deepika A., Bhattacharya, Sourav., & Das, Tapas K., *Perturbation of mass accretion rate, associated acoustic geometry and stability analysis*, New Astronomy **51**, 153, (2017).

13. Nag, Sankhasubhra., Sinha, Siddhartha., Ananda, Deepika B., & Das, Tapas K., *Influence of the black hole spin on the chaotic particle dynamics within a dipolar halo*, Astrophysics and Space Science **362**, Issue 4, article id.81, 8 pp., (2017).

14. Jyotiranjan Beuria, Arindam Chatterjee and AseshKrishna Datta, *Sbottoms of Natural NMSSM at the LHC,* JHEP 1608 (2016) 004.

15. Sabyasachi Chakraborty, AseshKrishna Datta, Katri Huitu, Sourov Roy and Harri Waltari, *Light top squarks in* $U(1)_R$*-lepton number model with a right handed neutrino and the LHC,* Phys.Rev. D93 (2016) no.7, 075005.

16. A. Bhattacharya, R Gandhi, A. Gupta and S. Mukhopadhyay, *Boosted Dark matter and its implications for the features in IceCube HESE data,* JCAP **1705, no 05**, 002, (2017).

17. D. Dutta, R Gandhi, B. Kayser, and M. Masud , *Capabilities of long baseline experiments in the presence of a sterile neutrino,* JHEP **1611**, 122, (2016).

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72. *A note on standard zero-free regions for Rankin-Selberg* L*-functions* (in preparation, with Satadal Ganguly (ISI Kolkata)).

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About the Computer Section

1. The computing facilities of the Institute are one of the best in the country. It provides the required support to the academics and research activities and to administrative activities. The computing facilities are available to users round the clock i.e $24 \times 7 \times 365$.

2. The entire HRI campus is connected with OFC based 1Gbps backbone providing the network and Internet connectivity to each and every office, hostel and guest house helping the scientists and all the other members on campus to work from any place in the campus even during night hours.

3. All the desktops of the faculty, students, post doctoral fellows and visiting fellows were upgraded with the newer version of Linux operating systems.

4. New versions of several applications software and packages were loaded on users' systems, computer centre systems and conference room systems, which provided the researchers to do their numerical and analytical calculations faster and obtain more precise results.

5. All the important packages were upgraded on Mail, Webmail, DNS, SSH, DHCP+DDNS, Proxy, LDAP and Firewall servers for the better, reliable and secure performance. Firewall rules were modified to increase the security level of the servers.

6. Some additional security features were added in the Mail Servers and other External Servers facing the Internet.

7. During the various conferences computer facilities were provided in the conference computer room to all the participants. Adequate computer support were provided to participants of the conferences.

8. Additional computing support was provided to the visiting scientists and visiting students under Visiting Students Programme (VSP) and Summer Programme in Mathematics (SPIM).

9. 10 desktop computers are being purchased for 2^{nd} year Ph.D. Students. All the other students, faculty members, administrative members, project staff and visitors are already having a desktop on their office desks.

Current activities and plans:

1. It is planned to further enhance the performance and security level of Mail, Webmail, NFS, LDAP and firewall servers.

2. It is planned to upgrade all the old Desktops of faculty members, students, post doctoral fellows and administrative members, with the two-year time line.

3. It is planned to purchase a colour printer for the computer centre users.

4. It is planned to upgrade the Video Conference System of the main meeting/discussion room of the Institute.

Library

The Institute has one of the best equipped libraries in the region. Being the library of a research Institute, it provides the required support to the academic and research activities. It remains open on working days, including saturday, from 8:00 a.m. to 2:00 a.m. It also remains open on Sundays and the gazetted holidays from 10:00 a.m. to 6:00 a.m. During the period from 1^{st} April 2016 to 31^{st} March 2017, it has added 311 (three hundred and eleven) books including 107 gifted books to its fold, increasing the total number of books to 22112 (twenty two thousand one hundred and twelve) which includes 1301 gifted books. It has also added 372 bound volumes of the journals, increasing its bound volume collection to 37201 (thirty seven thousand two hundred one). The library subscribed to 153 journals during this period, which includes 99 online journals. The library has subscribed the JSTOR, a digital library of academic journals and Project Euclid, a growing collection of high-impact, peer-reviewed titles in theoretical and applied mathematics and statistics. The library security has been strengthened with the implementation of electro-magnetic gate and tattle tapes.

The physical stock verification was recently completed with the help of PDT (Portable Data Terminal). The whole collection of documents is 'Bar coded and equipped with 'Tattle Tapes for security. It indicated loss of only two titles in the category of books.

We enriched Digital Library Repository of HRI, including submitted articles, thesis, lectures etc. The library web page has also been updated providing detailed information about the library such as subscribed databases, archives, library rules, library staff, list of online journals with their links, link to video lectures and other useful links. The emphasis was to procure maximum number of journals online. LibSys 7 is used as Library Management Software. Web enabled library catalogue has been provided to the users. The library is aiming to be entered as a 'Completely Automated Library System. The online catalogue has increased the opportunities of other institutions such as INSDOC, TIFR, IMSC etc, to use our library resources through the Document Delivery System (DDS). Normally DDS is provided on request by post, or by email.

Construction Activity

Activities related to building construction work from February-2013 is affected due to order of Honble High court in regard to PIL no. 4003 of 2006 related to Ganga pollution The Honble High Court has passed an order that no construction shall be carried out within the 500 meters of Highest Flood Level (HFL) of river Ganges in the year 1978. According to that, HRI fall within this prohibited range. HRI has filed an application in Court for relief against this order as HRI has its own Sewage Treatment Plant (STP) with almost zero discharge and cannot cause pollution to river Ganges. The decision of Court in our case is still awaited therefore since last four years all major construction activities are almost stopped.

Some miscellaneous works related maintenance/modifications were carried out during this financial year:-

1. Supply, installations, testing and commissioning of upgraded EPABX system with physical connectivity and configuration.

2. Rainwater harvesting system near Institute building.

3. SITC of Video Conferencing System for Conference Hall and New Lecture Hall (HIGGS) of the Library building.

4. Providing and fixing of filtration tank and related civil work in swimming pool.

5. Modification/Repairing work of watch towers installed near campus boundary wall.

6. SITC of intelligent fire alarm system for Computer centre.

7. Modification work (Making Platform and to separate cleaning area) in Kitchen area of Guest House.