National Level Academic Review

A Report for the period 2012-2017

- **ASTROPARTICLE PHYSICS AND COSMOLOGY (APC) DIVISION**
- **THEORY DIVISION**

National Level Academic Review

ASTROPARTICLE PHYSICS AND COSMOLOGY (APC) DIVISION

A Report for the period 2012-2017

Astroparticle Physics and Cosmology (APC) Division

Report of Academic activities during the period 2012-2017

1 Present Staff

	Scientific		Area of Research
1	Debades Bandyopadhyay Head	Sr. Professor H+	Neutron Star, Supernova
2	Pijushpani Bhattacharjee	Sr. Professor H+	Dark Matter (DM) and its phase-space distribution in the Galaxy; experimental search for WIMP DM; high energy γ-rays, neutrinos, cosmic rays
3	Debasish Majumdar	Professor G	Particle Dark Matter Models and Direct and Indirect signatures of DM, Dark Energy phenomenology, Neutrino Oscillation physics
4	Ambar Ghosal	Professor G	Neutrino mass models, Baryogenesis via Leptogenesis
5	Mala Das	Assoc. Professor F	Dark Matter search experiments, Detector development
6	Pratik Majumdar	Assoc. Professor E	Origin of cosmic rays, Very High Energy γ-ray Astrophysics, Very High Energy Neutrino astronomy, Instrumentation and Development of Novel Photodetectors

Technical - Mr. Nilanjan Biswas
Adm/Auxiliary - Mr. Bijoy Das

2 Post Doctoral Fellow

- Dr. Susnata Seth

3 Present Research Fellows

	Name of Student	Supervisor
1	Anshu Chatterjee	Pratik Majumdar
2	Rome Samanta	Ambar Ghosal
3	Roopam Sinha	Ambar Ghosal
4	Biswajit Banerjee	Pratik Majumdar
5	Sajjad Ahmad Bhat	Debades Bandyopadhyay
6	Madhurima Pandey	Debasish Majumdar

4 Ph.D. awarded

Serial No.	**Name of Student**	**Supervisor**	Present Address
1	Dr. Rana Nandi	Prof. Debades Bandyopadhyay	Frankfurt Institute for Advanced Studies
2	Dr. Srijit Bhattacharjee	Prof. Parthasarathi Majumdar	IIIT, Allahabad
3	Dr. Abhishek Majhi	Prof. Parthasarathi Majumdar	UNAM, Mexico
4	Dr. Lab Saha	Prof. Pijushpani Bhattacharjee	Universidad Complutense, Madrid
5	Dr. Soumini Chaudhury	Prof. Pijushpani Bhattacharjee	
6	Dr. Susmita Kundu	Prof. Pijushpani Bhattacharjee	
7	Dr. Susnata Seth	Prof. Pijushpani Bhattacharjee	SINP
8	Dr. Chandrachur Chakraborty	Prof. Debades Bandyopadhyay	TIFR
9	Dr. Apurba Kheto	Prof. Debades Bandyopadhyay	Maulana Azad College, Kolkata
10	Dr. Debabrata Adak	Prof. Debasish Majumdar	Singur College, WB
11	Dr. Mainak Chakraborty	Prof. Ambar Ghosal	Shiksha O Anusandhan Univ., Bhubaneswar
12	Dr. Anirban Biswas	Prof. Debasish Majumdar	HRI, Allahabad
13	Dr. Kamakshya Prasad Modak	Prof. Debasish Majumdar	B.K.C. College, Kolkata
14	Dr. Amit Dutta Banik	Prof. Debasish Majumdar	IIT, Guwahati
15	Dr. Prasanta Char	Prof. Debades Bandyopadhyay	LIGO-India, IUCAA

5 Major equipments and facilities

- Calibration system for calibrating the camera of the prototype Large Size Telescope of CTA
- High Performance computing cluster with 32 TB storage
- Precision voltage/current source & measurement unit
- Labview DAQ plus Accessories
- Bubble Detector – Personal Neutron Dosimeter

6 Research Outcome/Impact (2012-2017)

During the period of this report (2012-2017) the members of the APC Division have carried out research in a wide variety of projects in theoretical as well as experimental areas of Astroparticle Physics and Cosmology covering the following broad topics:

- Probing the matter and energy content of the Universe: Understanding the nature of Dark Matter (DM), Dark Energy (DE) and neutrinos, and experimental search for Dark Matter.
- Exploring the high energy Universe with high energy cosmic rays, gamma rays, X-rays and neutrinos.
- Testing fundamental theories of space-time and gravity with pulsars and black holes.

During the period under review the Division took up several new initiatives and directions of research:

- The APC Division in collaboration with the Applied Nuclear Physics Division of SINP took the lead role in the initiative to set up a Dark Matter search experiment, namely the DINO (Dark Matter@INO) experiment, in India. The DINO experiment proposes to search for the Weakly Interacting Massive Particle (WIMP) candidates of Dark Matter using scintillating crystal detectors. The first phase of the experiment (the so-called "mini-DINO" experiment with $\sim$ 5–10 kg of detector mass) is currently being set up at a location 550 m underground in the Jaduguda mine complex of the Uranium Corporation of India Ltd. (UCIL) under the Department of Atomic Energy (DAE), Government of India, in the state of Jharkhand, with the eventual goal of setting up a ton-scale experiment at the proposed India-based Neutrino Observatory (INO) in the future.

- The Division took the initiative in joining the international MAGIC (Major Atmospheric Gamma Imaging Cerenkov) Telescope collaboration for very high energy gamma-ray astronomy as a step towards eventually participating in the international Cerenkov Telescope Array (CTA) project, the up-coming largest ever imaging atmospheric Cerenkov telescope system for high energy gamma ray astronomy. The CTA project is widely regarded as a major step towards unraveling the century-old mystery of the origin of cosmic rays.

- Members from the APC Division members have joined the international Square Kilometer Array (SKA) project on radio astronomy and also in the GMRT-Pathfinder project - Pulsar and Transient Survey.

- In addition, the members of the Division have continued their active participation in the international PICO (earlier PICASSO) collaboration for Dark Matter search at SNOLAB underground facilities in Sudbury, Canada. The PICO is currently the world's most sensitive experiment searching for the spin-dependent (SD) interactions of the WIMP Dark Matter with nuclei.

Details of the research and development work carried out and important results obtained are given below:

Experimental Research:

6.1 Dark Matter Direct Detection Experiments

6.1.1 Search for Dark Matter with PICASSO/PICO

The international PICO/PICASSO collaboration, in which members from the APC division have been actively participating since about last eight years, searches for the WIMP candidates of DM using highly sensitive bubble chambers at the deepest underground ultra clean facility of SNOlab, Sudbury, Canada. The PICO chambers are refined versions of classical bubble chambers operated at moderate superheat and with exquisite control of radioactive backgrounds. The low detection threshold, excellent sensitivity to low mass WIMPs, the interchangeability of the target fluid, and high intrinsic background rejection capability make PICO unique in the field of direct detection of WIMPs and complementary to the physics capabilities of other WIMP DM search experiments. The PICASSO collaboration, which ran until 2014, has already published world leading limits on spin-dependent (SD) interaction of WIMPs with nuclei, and the members of the APC division of SINP have made significant contributions in this effort.

The PICO collaboration was formed in 2013 with the merger of the PICASSO and COUPP collaborations. The SINP group, currently led by Mala Das, is a continuing member of the PICO collaboration and is actively engaged in various aspects of the experiment including hardware, data analysis, simulation and so on. Brief descriptions of the major contributions made by the SINP group in PICASSO/PICO collaboration are given below:

• The simulation of the response of the superheated droplet detector to alpha particles performed at SINP led to the identification of the sources of the observed two different thresholds of the detector: one threshold was identified to be due to nuclear recoils caused by alphas present as contamination in the active liquid, and the other was identified as that due to alpha particles present both in the supporting matrix and in the active liquid.

• Simulations have been performed to determine the nucleation parameter for heavy ion induced bubble nucleation in superheated droplet detectors for understanding the bubble nucleation process and compared with experimental results.

• Alpha particle induced bubble nucleation events are the main source of the background in the PICASSO detector and have to be separated from the nuclear recoil induced events. With this aim, alpha-neutron discrimination has been studied experimentally at SINP-lab and the parameters defining the discrimination were found. To improve the resolution of discrimination between the alpha- and neutron induced events, the method of "event time correction" during the data run was developed at SINP and applied to the analysis of PICASSO data.

• Experiments and simulations have also been performed to distinguish between gamma and neutron induced events in superheated droplet detectors and several parameters for the possible discrimination were studied.

• Detection of bubble nucleation events in superheated droplet detector using pressure sensors has been explored.

• The universal nature of the energy calibration curve for superheated liquid detectors made of different liquids has been established employing the concepts of "reduced" superheat and "effective" recoil nuclei.

• Recently, the mechanical design of the camera holding system for viewing the bubble nucleation for the upcoming PICO-40/500 chamber has been completed by SINP.

In June 2017, the PICO collaboration has published the most stringent upper limit on the WIMP-proton spin-dependent cross section at $3.4 \times 10^{-41}\,\mathrm{cm}^2$ for a WIMP mass of $\sim 30\,\mathrm{GeV}$.

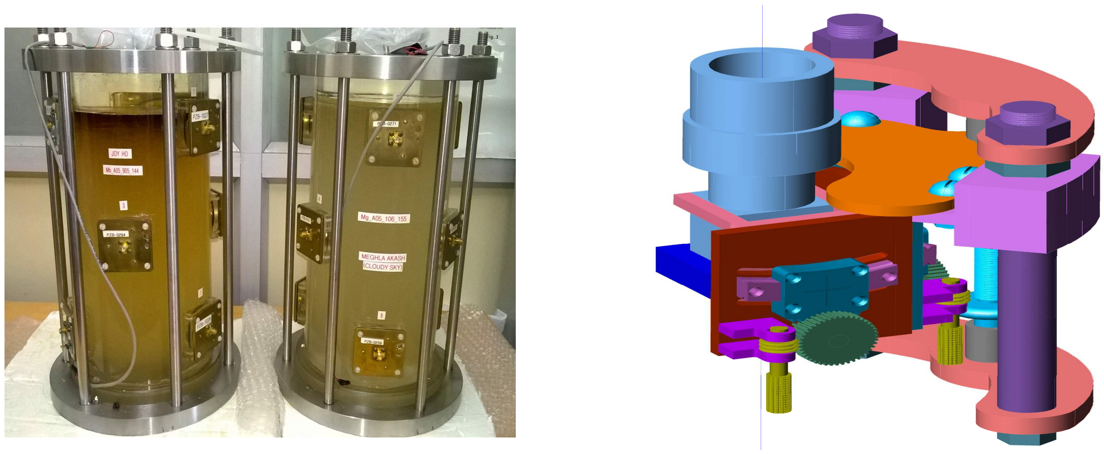

Figure 1: *Left panel*: PICASSO detector modules fabricated by the SINP group. *Right panel*: Mechanical design, done at SINP, of the camera holding system for viewing bubble nucleation events for the upcoming PICO-40/500 chamber.

6.1.2 The Dark Matter@INO (DINO) experiment

As already mentioned, the first phase of the proposed DINO Dark Matter search experiment, namely, the mini-DINO experiment, is currently being set up at a location 550m underground at the Jaduguda mine complex. The experiment aims to use suitable scintillating crystalline materials with a combination of elements having a broad range of atomic masses so as to be sensitive to WIMPs in a broad range of masses from few GeV to few hundred GeV. It is envisaged to detect scintillation light as well as heat pulses (ballistic phonons) in order to effectively discriminate between nuclear recoil (due to WIMPs) and electron recoils (due to background). R&D work is being done with CsI and GGAG scintillating crystals as possible detector materials in view of their relatively high scintillation light output. Photo-multiplier tubes (PMT) as well as new generation silicon photomultipliers (SiPMs) are being used for detecting the scintillation light. It is planned to use suitable transition edge sensors (TES) or superconducting phase thermometer (SPT) for detection of phonons caused by nuclear recoils.

APC Division members are currently involved in the simulation of radiogenic and cosmogenic neutron backgrounds at the experiment site, these neutrons being the most important background for the WIMP search experiment. The APC Division members are also involved in studying the neutron and gamma response of the scintillating crystal detector to be used in the experiment.

6.2 Exploring the high energy Universe with high energy cosmic rays and very high energy gamma rays

The origin of cosmic rays (CRs) has been one of the enigmatic problems in astrophysics since its discovery in 1912 by Victor Hess and has remained unresolved since more than 100 years. Detectors for charged cosmic rays, high energy gamma-rays and neutrinos are used to investigate the high energy phenomena occurring at cosmic accelerators with the hope to unveil an unsolved mystery and probe at the same time the laws of physics under extreme condition of gravity, pressure and density in a way not accessible with terrestrial laboratories.

Very High Energy (VHE) γ-ray astrophysics started primarily in the context of sources of cosmic ray particles which are the progenitors of γ-rays. More than 150 high energy gamma ray sources of various genre have been discovered in the last decade. The last decade has also witnessed the linkage of ground based and space based platforms for GeV-TeV astronomy and massive coordinated multi-wavelength observation campaigns in order to study these sources. In short, the three most outstanding questions of TeV γ-ray astrophysics today are

- Origin of Cosmic rays : solving the 100 year old problem
- How transparent is our Universe : Cosmology with TeV gamma rays and Understanding the Extragalactic Background Light (EBL)
- Indirect Detection of Dark Matter

The present generation of ground based gamma-ray telescopes (the three current leading installations being H.E.S.S. in the southern hemisphere and MAGIC and VERITAS telescope system in the northern hemisphere) have given a wealth of data and have produced impressive physics results in each of these areas. The impressive physics results obtained with the present generation instruments have triggered the initiative of astroparticle physicists all over the world to build the next-generation ground based gamma-ray telescopes with improvements in sensitivity over the current generation of telescopes (H.E.S.S, MAGIC, VERITAS) by at least a factor 10. Such systems will be able to make measurements of the gamma ray sky in unprecedented detail from 10 GeV to 200 TeV thus complementing the ongoing Fermi satellite experiment from 50 MeV to > 100 GeV. This has led to the establishment of an international collaboration for setting up an array of Cherenkov telescopes, called the Cherenkov Telescope Array (CTA), one each in the southern and northern hemispheres [1] which will cover an en-

[1] The site at southern hemisphere under negotiation is Paranal, Chile and the site in the northern hemisphere is La Palma, Canary Islands, Spain. The backup sites in the south and north are Namibia and Mexico respectively. These sites were chosen after intense site survey across all parts of the world which also involved the site in India, Hanle at an altitude of 4000 mts

ergy range of 10 GeV to 200 TeV. It is also clear from the current knowledge of operations of Cherenkov telescopes and performing large scale Monte Carlo simulations that a mixed array [2] is required to achieve the best sensitivity over a wide energy range spanning over 4 decades in energy.

CTA will focus on the physics of the cosmic accelerators both in our galaxy and outside our galaxy and will shed valuable insights into the 100 year old cosmic ray origin problem. It will also search for the elusive dark matter particles in the cosmos and will probe the evolution of the intervening universe by putting stringent constraints on the optical/infra-red background radiation through observations of near and far galaxies. In addition, it will also focus on a number of fundamental physics issues like deriving constraints on TeV to Planck-scale physics inaccessible to terrestrial experiments through observations of fast flares from active galactic nuclei (AGNs) and gamma-ray bursts (GRBs).

Since the start of the 12^{th} 5-year plan, the scientists from the Astroparticle Physics and Cosmology Division of Saha Institute of Nuclear Physics (SINP) have been working with the simulation working group of CTA in order to understand the sensitivity of such an array. As regards hardware, SINP has led the efforts in the design and assembly of a system required to calibrate the camera of a prototype Large Size Telescope (LST) in close collaboration with the members from MAGIC telescope collaboration led by Max Planck Institute for Physik, Munich, Germany and Tata Institute of Fundamental Research, Mumbai. Pratik Majumdar served as the *Technical responsible* person for the design and development of a calibration system which has been completed in early 2017 and has been extensively tested and characterized. The construction and commissioning of the LST within CTA is the responsibility of the members of the MAGIC collaboration which forms the core of the CTA consortium. The SINP group, led by Pratik Majumdar, formally joined the MAGIC collaboration in 2016, and has since been actively contributing to various hardware, software and science related activities of the collaboration as described in more details below:

6.2.1 Software and Monte Carlo (MC) Simulations

One of the most important areas where we focus on is to understand the performance of the MAGIC telescopes, namely the point spread function of the telescope and the absolute light calibration of the telescopes using muon rings. To achieve this goal, extensive simulations are done using muons generated in the atmosphere. For generation of the muons, we use CORSIKA simulation package which is routinely used by astroparticle physicists. The Cherenkov light generated by muons is then further processed through the detector simulation package and

[2] mixed array means a suitable combination of Large Size Telescopes (LST), Medium Size Telescopes (MST) and Small Size Telescope (SST)

finally images of muons on the camera of the telescope are analyzed and then compared with those from the data. From the MC-data comparisons of the various parameters of these muon images, estimates of the point spread function of the telescope and light collection efficiency of the telescopes can be ascertained. This information is extremely valuable in following the long term performance of the telescope system. Using the long-term performance evaluation, we provide significant feedback to the people involved in the maintenance and upgrades of the hardware of MAGIC telescopes.

To carry out this work successfully, one requires adequate computing and storage resources. For this purpose, the APC Division has recently installed a computing cluster consisting of about 100 CPUs and 30 TB disk space, where all the MC generation of events and subsequent analysis can be carried out.

The extensive knowledge gained in this work enabled the SINP group led by Pratik Majumdar to participate in framing and writing the Technical Design Report of the various calibration methodologies pertaining to the upcoming telescope arrays like CTA where SINP group's work has been well documented in an internal note of CTA calibration group and some of this work has also been presented in conferences by members of the consortium.

Currently Pratik Majumdar is serving as one of the members of the Software Board of the MAGIC telescope collaboration. This is an ongoing responsibility which he took over in 2015 and has been successfully performing the duty as part of regular duties of the collaborative project. Pratik Majumdar is currently also serving as the Working Group leader of the Galactic Physics working group of the MAGIC telescope collaboration.

6.2.2 Hardware Activities

Pratik Majumdar is the technical responsible person for designing and developing the calibration system for calibrating the camera of the prototype Large Size Telescope (LST). The calibration system has been designed, developed and assembled with help of engineers and technicians at SINP and TIFR and a graduate student (Anshu Chatterjee) from SINP. This work will form a significant part of the graduate student's thesis. The calibration system has been tested extensively and all tests to ascertain its performance are nearing completion. It is expected to be shipped to the observatory at La Palma, Canary Islands, Spain in autumn 2017 where the prototype LST is being constructed. Further field tests are envisaged in 2017 and 2018. The details of the calibration system and its characterization have been documented in various internal presentations and International Cosmic Ray Conference (ICRC) proceedings (see publication list).

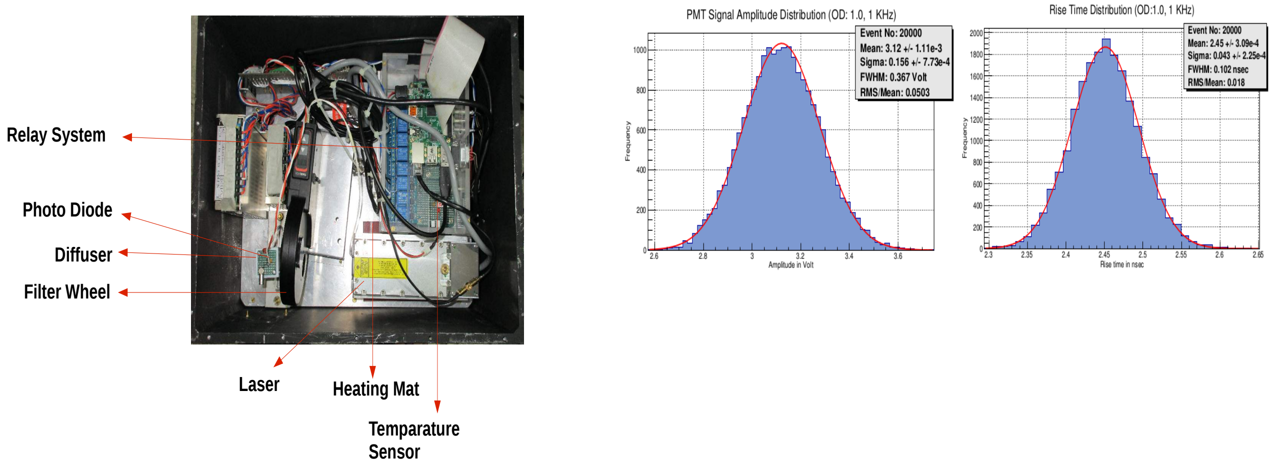

Figure 2: *Left panel*: Photo of the calibration system designed and assembled by scientists at SINP for Large Size Telescope of CTA to be installed at La Palma, canary Islands, Spain. *Right panel*: Amplitude and rise-time distributions of the pulses from the calibration box

6.2.3 Physics Analysis

• Probing the origin of galactic cosmic rays with Supernovae Remnants:
It is widely believed that supernova remnants (SNRs) are sources of galactic CRs and they are accelerated in the shocks of supernovae by diffusive shock acceleration mechanism. Some of the observed SNRs show significant emission in all wavebands. Non-thermal radio and X-ray fluxes from these sources already established the fact that electrons are accelerated in both forward and reverse shocks inside those remnants. Moreover, acceleration of charged particles to multi-TeV energies in various SNRs has been confirmed by detection of TeV gamma rays by current generation of ground based TeV instruments. In spite of this progress, there had been no serious discussion on the spectral and spatial structures of the source in high energy gamma-rays and their correlation with the observed radio and X-ray fluxes. We analyzed multiwavelength data from the famous supernova remnant Cas A and modeled the emission regions of the source based on radio, X-rays and GeV-TeV gamma rays. Our aim is to locate the emission region of TeV gamma rays by analyzing the different regions of the shell of the remnant. We found that a simple leptonic model is unable to explain the GeV-TeV emission simultaneously and we henceforth invoke a hadronic model and a lepto-hadronic model and showed that these models can describe the data better.

A group of middle-aged mixed-morphology (MM) supernova remnants (SNRs) interacting with molecular clouds (MCs) has been observed to be strong GeV gamma-ray emitters by the Large Area Telescope (LAT) on board the Fermi Gamma-Ray Space Telescope (Fermi-LAT).

The recent observations of the Suzaku X-ray satellite have revealed that some of these interacting gamma-ray-emitting SNRs, such as IC443, W49B, W44, and G359.1-0.5, have overionized plasmas. We concentrated on to study a few mixed-morphology SNRs in order to probe the origin of galactic cosmic rays in these sources.

3C 391 (G31.9+0.0) is one such galactic MM SNR interacting with MCs. It was observed in GeV gamma rays by Fermi-LAT as well as in the 0.3-10.0 keV X-ray band by Suzaku. In our work, 3C 391 was detected in GeV gamma rays with a significance of 18σ and we showed that the GeV emission is point-like in nature. The GeV gamma-ray spectrum was shown to be best explained by the decay of neutral pions assuming that the protons follow a broken power-law distribution. We revealed radiative recombination structures of silicon and sulfur from 3C 391 using Suzaku data. In our paper, we discuss the possible origin of this type of radiative plasma and hadronic gamma rays.

Another MM SNR, G349.7+0.2, was detected in the energy range of 0.2-300 GeV with a significance of $\sim 13\ \sigma$, showing no extended morphology. Modeling of the gamma-ray spectrum revealed that the GeV gamma-ray emission dominantly originates from the decay of neutral pions, where the protons follow a broken power-law distribution with a spectral break at $\sim$ 12 GeV. To search for features of radiative recombination continua in the eastern and western regions of the remnant, we analyzed the Suzaku data of G349.7+0.2 and found no evidence for overionized plasma. [Pratik Majumdar (SINP) in collaboration with Tulun Ergin (Tübitak Space Technologies Research Institute, Turkey), Lab Saha (University Complutense, Madrid), M. Bozkurt (Bogazici University, Physics Department, Turkey).]

• Observations of HAWC sources in the sub-TeV energy ranges with the MAGIC telescopes :

The High Altitude Water Cherenkov (HAWC) detector array has recently released a catalog of very high energy gamma-ray sources above an energy threshold of $\sim$ 10 TeV which have no clear counterparts in lower energies (either at $>$ 10 GeV or $>$ 300 GeV). We used the MAGIC telescopes and archival data from Fermi-LAT satellite detector to search for high energy and very high energy gamma ray emission from a selected list of promising candidate sources. We did not detect any significant emission of gamma rays from any of the candidate sources and hence we calculated differential flux upper limits for these sources. The combination of Fermi-LAT, HAWC and MAGIC results together will allow us to put strong constraints on the extensions of the sources. Anshu Chatterjee, PhD student in the group, is one of the analyzers for this work and a paper is currently under preparation to be submitted to the collaboration to be reviewed for a publication. [Anshu Chatterjee (SINP), Oscar Blanch (IFAE, Barcelona, Spain), Alba Fernandez (IFAE, Barcelona, Spain), and MAGIC collaboration.]

• Analysis of the bright High Frequency BL Lac AGN Mrk 421

We have proposed observations on bright High Frequency BL Lac (HBL) objects, Mrk 421, Mrk 501 with the MAGIC telescope system in order to study particle acceleration and the nature of TeV gamma-ray emission in these objects. We have detected Mrk 421 in one of its historical low-states ($< 10\%$ of the Crab nebula flux) during one of our observational campaigns in early 2015. Over the last 2 years, we have collected a large amount of data on the source and further multiwavelength data analysis (X-rays, radio, optical) is in progress in order to understand the nature of gamma-ray emission from this source. This will form the major part of PhD thesis of Biswajit Banerjee who is the leading analyzer for the source Mrk 421. [Biswajit Banerjee (SINP), David Paneque (MPI für Physik, Munich) and MAGIC collaboration.]

• Long term Lightcurve of blazar PKS1510-089

We have analyzed data from the Flat Spectrum Radio Quasar PKS 1510-089 collected over a period of 8 years from August 2008 to December 2016 with the Fermi-LAT. We have identified several flares of this highly variable source, studied their temporal and spectral properties in detail and compared with previous works on flares of PKS 1510-089. Five major flares and few sub-flares/sub-structures have been identified in our study. The fastest variability time is found to be 1.30 ± 0.18 hr where we estimate the minimum size of the emission region to be 4.85×10^{15} cm. In most of the flares the spectral energy distributions are better fitted with log-parabolic distribution compared to a simple power law or power law with exponential cut-offs. This has strong physics implications regarding the nature of the high energy gamma-ray emission region. [Pratik Majumdar (SINP) with Raj Prince (RRI, Bangalore), and Nayantara Gupta (RRI, Bangalore).]

• Analysis and modeling of young and middle aged Pulsar wind nebulae

The increasing sensitivity of current generation of telescopes in X-ray and GeV-TeV energies has revealed a large number of nebulae associated with pulsars. However, these pulsar wind nebulae still do not show a uniform behaviour in terms of their parameters like luminosity, magnetization etc. In order to explore the possible existence of common evolutionary trends and to link the characteristics of nebula emission with that of the pulsar, we have been involved in detailed analysis of data from the MAGIC telescopes on a few selected pulsar wind nebula systems. We have also been working on a leptonic time-dependent modeling of GeV-TeV detected young and middle aged pulsar wind nebulae.

[Anshu Chatterjee (SINP) and L. Saha (University Complutense, Madrid).]

Theoretical Research:

6.3 TeV Gamma rays, pulsars

- **Constraints on the synchrotron self-Compton mechanism of TeV gamma ray emission in the pulsar wind nebula scenario :**
  Origin of the TeV gamma ray emission from MGRO J2019+37 discovered by the Milagro experiment is investigated within the pulsar wind nebula (PWN) scenario using multiwavelength information on sources suggested to be associated with this object. It is found that the synchrotron self-Compton (SSC) mechanism of origin of the observed TeV gamma rays within the PWN scenario is severely constrained by the upper limit on the radio flux from the region around MGRO J2019+37 given by the Giant Metrewave Radio Telescope (GMRT) as well as by the x-ray flux upper limit from SWIFT/XRT. Specifically, for the SSC mechanism to explain the observed TeV flux from MGRO J2019+37 without violating the GMRT and/or Swift/XRT flux upper limits in the radio and x-ray regions, respectively, the emission region must be extremely compact with the characteristic size of the emission region restricted to $\lesssim O(10^{-4})$ pc for an assumed distance of $\sim$ few kpc to the source. This is at least four orders of magnitude less than the characteristic size of the emission region typically invoked in explaining the TeV emission through the SSC mechanism within the PWN scenario. On the other hand, inverse Compton (IC) scattering of the nebular high energy electrons on the cosmic microwave background (CMB) photons can, for reasonable ranges of values of various parameters, explain the observed TeV flux without violating the GMRT and/or SWIFT/XRT flux bounds. [Lab Saha and Pijushpani Bhattacharjee, Jour. High Energy Astrophys. (JHEAP) **5–6**, 9–14 (2015)].

- **A study of the performance parameters of the High Altitude Gamma Ray (HAGAR) telescope system at Ladakh in India :**
  The results of Monte Carlo simulations for the High Altitude Gamma Ray (HAGAR) telescope array which detects very high energy gamma rays from astronomical sources are presented. This telescope array, located at Hanle at an altitude of 4270 m in the Ladakh region of the Himalayas in India, is one of the highest altitude atmospheric Cherenkov experiments in the world. Taking advantage of the high altitude, this experiment could achieve relatively low energy threshold with a modest mirror area coverage. To understand the performance parameters of this telescope system, large samples of extensive air showers initiated by gamma rays and various species of cosmic rays are simulated using the CORSIKA package. Cherenkov photons produced in the atmosphere are sampled

at ground level. These photons are then passed through the detector simulation program, which takes into account various design details and the data acquisition system of HAGAR. Night sky photons are also considered in the detector simulation program as performance of the telescope depends strongly on the level of night sky background (NSB) at the observation site. Various performance parameters like energy threshold and effective area for vertically incident showers as well as inclined showers are estimated from the results of these simulations. Details of these parameters, results obtained from simulations and comparison with the observed data are presented. It is shown that the energy threshold of the HAGAR telescope system is about 208 GeV, a factor of ~ 4 less than for a similar set up at about 1000 m altitude, and it is able to detect Crab like sources at 5σ significance in 17 h of observation without imposing additional criteria like gamma-hadron separation for further rejection of cosmic rays. [L. Saha et al. (HAGAR collaboration), *Astropart. Phys.* **42**, 33-40 (2013)].

6.4 Dark Matter

6.4.1 Dark Matter Astrophysics

- **Rotation curve of the Milky Way out to 200 kpc :**
  The rotation curve (RC) of the Milky Way, from its inner regions (galactocentric distance of few hundred parsecs) out to a galactocentric distance of ~ 200 kpc, the largest distance considered so far in this context, is derived using kinematical data on a variety of tracer objects moving in the gravitational potential of the Galaxy. Amongst other results it is found that the mean RC of the Galaxy steadily declines at distances beyond ~ 60 kpc. A lower limit to the total mass of the Galaxy within ~ 200 kpc, namely, $M(200\,\mathrm{kpc}) \gtrsim (6.8 \pm 4.1) \times 10^{11} M_{\odot}$, is derived independently of any model of the Dark Matter halo of the Galaxy. These results have important implications for the total amount and distribution of the Dark Matter in the Galaxy. [P. Bhattacharjee, S. Chaudhury and S. Kundu, *Astrophysical Journal*, **785** (2014) 63].

- **Deriving the velocity distribution of Galactic dark matter particles from the rotation curve data :**
  The velocity distribution function (VDF) of the weakly interacting massive particle (WIMP) candidates of the Dark Matter (DM) in the Galaxy is determined directly from the circular speed ("rotation") curve data of the Galaxy assuming isotropic VDF. This is done by "inverting" — using Eddingtons method — the Navarro-Frenk-White universal density profile of the DM halo of the Galaxy, the parameters of which are determined by using the

Markov chain Monte Carlo technique from observational data on the Galaxy's rotation curve extended to distances well beyond the visible edge of the disk of the Galaxy. The derived most-likely local isotropic VDF is found to significantly differ from the Maxwellian form assumed in the "standard halo model" customarily used in the analysis of the results of WIMP direct-detection experiments. A parametrized (non-Maxwellian) form of the derived most-likely local VDF is given. The astrophysical "g factor" that determines the effect of the WIMP VDF on the expected event rate in a direct-detection experiment can be significantly lower for the derived most-likely VDF than that for the best-fit Maxwellian at the lowest WIMP mass threshold of a typical experiment. [P. Bhattacharjee, S. Chaudhury, S. Kundu and S. Majumdar, *Phys. Rev. D* **87**, 083525 (2013)].

- **Neutrinos from WIMP annihilations in the Sun: Implications of a self-consistent model of the Milky Way's dark matter halo :**
Upper limits on the spin-independent (SI) as well as spin-dependent (SD) elastic scattering cross sections of low mass (∼ 2 - 20 GeV) weakly interacting massive particle (WIMP) candidates of dark matter (DM) with protons, imposed by the upper limit on the neutrino flux from WIMP annihilation in the Sun given by the Super-Kamiokande (S-K) experiment, and their compatibility with the "DAMA-compatible" regions of the WIMP parameter space — the regions of the WIMP mass versus cross-section parameter space within which the annual modulation signal observed by the DAMA/LIBRA experiment is compatible with the null results of other direct-detection experiments — are studied within the framework of a self-consistent model of the finite-size DM halo of the Galaxy. The halo model includes the gravitational influence of the observed visible matter of the Galaxy on the phase-space distribution function of the WIMPs constituting the Galaxy's DM halo in a self-consistent manner. Unlike in the "standard halo model" (SHM) used in earlier analyses, the velocity distribution of the WIMPs in our model is non-Maxwellian, with a high-velocity cutoff determined self-consistently by the model itself. The parameters of the model are determined from a fit to the rotation curve data of the Galaxy. It is found that, for our best-fit halo model, for SI interaction, while the S-K upper limits do not place additional restrictions on the DAMA-compatible region of the WIMP parameter space if the WIMPs annihilate dominantly to $\bar{b}b$ and/or $\bar{c}c$, portions of the DAMA-compatible region can be excluded if WIMP annihilations to $\tau^+\tau^-$ and $\bar{\nu}\nu$ occur at larger than 35% and 0.4% levels, respectively. For SD interaction, on the other hand, the restrictions on the possible annihilation channels are much more stringent: they rule out the entire DAMA region if WIMPs annihilate to $\tau^+\tau^-$ and $\bar{\nu}\nu$ final states at greater than $\sim$ 0.05% and 0.0005% levels, respectively, and/or to $\bar{b}b$ and $\bar{c}c$ at greater than $\sim$

0.5% levels. Subsequent results from the S-K Collaboration [T. Tanaka et al., Astrophys. J. 742, 78 (2011)] have made the above constraints on the branching fractions of various WIMP annihilation channels even more stringent by roughly a factor of 3-4. [Susmita Kundu and Pijushpani Bhattacharjee, Phys. Rev. **D 85**, 123533 (2012)].

6.4.2 Particle Dark Matter and phenomenology

- We consider a simple extension of Standard Model in which a real Standard Model gauge singlet scalar with an additional discrete symmetry Z_2 is introduced to SM. This additional scalar, S, can be a viable candidate of cold dark matter since the stability of S is achieved by the application of Z_2 symmetry on S. Considering S as a possible candidate of cold dark matter we have solved Boltzmann equation to find the freeze out temperature and relic density of S in the scalar mass range 5 GeV to 1 TeV. As HHSS coupling δ_2 appearing in Lagrangian depends upon the value of scalar mass m_S and Higgs mass m_h, we have constrained the $m_S\delta_2$ parameter space by using the WMAP limit on the relic density of dark matter in the universe and the results of recent ongoing dark matter direct search experiments namely CDMS-II, CoGeNT, DAMA, EDELWEISS-II, XENON-10, XENON-100. From such analysis we find two distinct mass regions (a lower and higher mass domain) for such a dark matter candidate that satisfy both the WMAP limit and the experimental results considered here. We have estimated the possible differential direct detection rates and annual variation of total detection rates for this scalar dark matter candidate S for two detector materials namely Ge, Xe. Finally we have calculated the γray flux from the galactic centre due to annihilation of two 130 GeV scalar dark matter into two monoenergetic γrays.

- There has been observational evidence of a gamma-ray line at 130 GeV originated from the galactic centre. This is revealed after the analysis of the Fermi-LAT satellite data. Being monochromatic in nature, it rules out the possibility of having its astrophysical origin, and there has been a speculation that this γ-line could be originated from dark matter annihilation in the galactic centre region. In this work, we propose a two component dark matter scenario. The two dark matter candidates are proposed by an extension of the Standard Model by adding an inert Higgs doublet and a gauge singlet scalar. For them to be viable dark matter candidates, a $Z_2 \times Z_2'$ symmetry, is imposed on added inert doublet and scalar singlet. The relic density of such a dark matter is now complicated we have to solve two coupled Boltzmann equation for the purpose. We find that our scenario can not only explain the 130 GeV gamma-ray line through dark matter annihilation but also produce the proper fractional dark matter relic densities of each component which add up to obtain the observed dark matter relic density.

- A lightest supersymmetric particle (LSP), namely, the neutralino, in minimal anomaly mediated supersymmetry breaking model (mAMSB) is considered to be a possible candidate for weakly interacting massive particles (WIMP) or cold dark matter. The theoretically allowed supersymmetric parameter space for such a model along with the recent bounds from LHC is constrained by the WMAP results for relic densities. The spin independent and spin dependent scattering cross sections for dark matter off nucleon are thus constrained from the WMAP results. They are found to be within the allowed regions of different ongoing direct detection experiments. The annihilations of such dark matter candidates at the galactic centre produce different standard model particles such as gamma rays, neutrinos etc. In this work, we calculate the possible fluxes of these γ-rays and neutrinos coming from the direction of the galactic centre (and its neighbourhood) at terrestrial or satellite borne detectors. The calculated γ-ray flux is compared with the observational results of HESS experiment. The neutrino flux of different flavours from the galactic centre and at different locations away from the galactic centre produced by WIMP annihilation in this model are also obtained for four types of galactic dark matter halo profiles. The detection prospects of such neutrinos coming from the direction of the galactic centre at the ANTARES under sea detector are discussed in terms of muon signal yield from these muon neutrinos. Both the gamma and neutrino signals are estimated for four different dark matter halo profiles.

- A fermion instead of a scalar is considered as a candidate of dark matter in Two Higgs Doublet Model (THDM) where THDM is extended by adding singlet fermion to THDM. We explore the viability of this singlet fermion to be a candidate for dark matter in the framework of THDM. Adding a singlet fermion to the SM Lagrangian we extend this model in the framework of THDM. The stability of the added fermion as the proposed dark matter candidate is ensured by assigning the baryon and lepton charge f of the singlet to be zero. A discrete symmetry is introduced between higgs doublets to avoid flavour changing neutral current (FCNC) processes. Both the singlet fermion and the DM candidate couple to both higgs doublets through a dimension 5 coupling when a new physics scale Λ is introduced.

- In recent years lot of interest has been taken to explain the excess gamma rays observed mainly by the satellite-borne experiments from the direction of the galactic centre as also from the "Fermi Bubble". As the known astrophysical effects fail to explain the observed excess in gamma rays, the proposition that these gamma ray excesses are due to dark matter annihilation at the galactic centre region is fast gaining ground. To this end, a dark matter model is proposed in order to explain simultaneously the observed gamma ray excess from galactic centre region at gamma ray energy (E_γ) at 10 GeV and similar excess at $E_\gamma \sim 1-2$ GeV for gamma rays from Fermi bubble. Fermi bubble actually is referred to as two gamma ray emitting zones in the shape of two bubbles that originate from the galactic centre and extend above and below the galactic plane. Our proposed dark matter model is a two component model in which dark matter has two particle components which in our case are considered as scalar singlets. Our model could beautifully explain the above mentioned phenomena of gamma excess.

- A particle dark matter is considered where an extra inert Higgs doublet and an additional scalar singlet is added to the Standard Model (SM) Lagrangian. The dark matter candidate is obtained from only the inert doublet. The stability of this one component dark matter is ensured by imposing a Z_2 symmetry on this additional inert doublet. The additional singlet scalar has a vacuum expectation value (VEV) and mixes with the Standard Model Higgs doublet resulting in two CP even scalars h_1 and h_2. We treat one of these scalars, h_1, to be consistent with the SM Higgs like boson of mass around 125 GeV reported by the LHC experiment. These two CP even scalars contribute to the annihilation cross-section of this inert doublet dark matter resulting in a larger dark matter mass region that satisfies the observed relic density. We also investigate the $h_1 \to \gamma\gamma$ and $h_1\gamma Z$ processes and compared these with LHC results. This is also used to constrain the dark matter parameter space in the present model. It is found that the dark matter candidate in the mass region $\frac{m_1}{2} < m_H < m_W$ ($m_1 = 125$ GeV, mass of h_1) satisfies the recent bound from LUX direct detection experiment.

- A dark matter model is proposed where an inert doublet and a scalar singlet is added to the Standard Model. Here the dark matter candidate is the inert doublet particle while the scalar singlet develops vacuum expectation value. We show that in such a model, the dark matter candidate with mass 35 GeV can well explain the observed gamma ray excess from the galactic centre region at the gamma energy $E_\gamma \sim 1-3$ GeV. The 35 GeV dark matter in our formalism can also explain the Planck relic density results, the direct detection experimental results as also the bounds obtained from LHC experiment.

- A two component model of nonthermal dark matter is formulated to simultaneously explain the Fermi-LAT results indicating a γ-ray excess observed from our Galactic Centre in the $1-3$ GeV energy range and the detection of an X-ray line at 3.55 keV from extragalactic sources. Two additional Standard Model singlet scalar fields S_2 and S_3 are introduced. These fields couple among themselves and with the Standard Model Higgs doublet H. The interaction terms among the scalar fields, namely H, S_2 and S_3, are constrained by the application of a discrete $Z_2 \times Z_2'$ symmetry which breaks softly to a remnant Z_2'' symmetry. This residual discrete symmetry is then spontaneously broken through an MeV order vacuum expectation value u of the singlet scalar field S_3. The resultant physical scalar spectrum has the Standard Model like Higgs as χ_1 with $M_{\chi_1} \sim 125$ GeV, a moderately heavy scalar χ_2 with $50\,\mathrm{GeV} \leq M_{\chi_2} \leq 80\,\mathrm{GeV}$ and a light scalar χ_3 with $M_{\chi_3} \sim 7$ keV. There is only tiny mixing between χ_1 and χ_2 as well as between χ_1 and χ_3 . The lack of importance of domain wall formation in the present scenario from the spontaneous breaking of the discrete symmetry, provided $u \leq 10$ MeV, is pointed out. We find that our proposed two component dark matter model is able to explain successfully both the above mentioned phenomena the Fermi-LAT observed γ-ray excess (from the $\chi_2 \to b\bar{b}$ decay mode) and the observation of the X-ray line (from the decay channel $\chi_3 \to \gamma\gamma$) by the XMM-Newton observatory.

- Recent data from Reticulum II (RetII) *Dwarf Galaxy* require the energy range of the FermiLAT gamma-excess to be $\sim$ 210 GeV. We adjust our unified nonthermal Dark Matter (DM) model (mentioned above) to accommodate this. We have two extra scalars beyond the Standard Model to also explain the 3.55 keV X-ray line. Now the mass of the heavier of them has to be increased to lie around 250 GeV, while that of the lighter one remains at 7.1 keV. This requires a new seed mechanism for the gamma-excess and new Boltzmann equations for the generation of the DM relic density. All concerned data for RetII and the X-ray line can now be fitted well and consistency with other indirect limits attained.

- We propose the existence of a hidden or dark sector besides the standard model (SM) of particle physics, whose members (both fermionic and bosonic) obey a local $\mathrm{SU(2)_H}$ gauge symmetry while behaving like a singlet under the SM gauge group. However, the fermionic fields of the dark sector also possess another global $\mathrm{U(1)_H}$ symmetry which remains unbroken. The local $\mathrm{SU(2)_H}$ invariance of the dark sector is broken spontaneously when a scalar field in this sector acquires a vacuum expectation value (VEV) and thereby generating masses to the dark gauge bosons and dark fermions charged under the $\mathrm{SU(2)_H}$. The lightest fermion in this dark $\mathrm{SU(2)_H}$ sector can be a potential dark matter candidate. We first examine the viability of the model and constrain the model parameter space by theoretical constraints such as vacuum stability and by the experimental constraints such as PLANCK limit on relic density, LHC data, limits on spin independent scattering cross-section from dark matter direct search experiments etc. We then investigate the gamma rays from the pair annihilation of the proposed dark matter candidate at the Galactic Centre region. We also extend our calculations of gamma rays flux for the case of dwarf galaxies and compare the signatures of gamma rays obtained from these astrophysical sites.

- We explore a two component dark matter model with a fermion and a scalar. In this scenario the Standard Model (SM) is extended by a fermion, a scalar and an additional pseudo scalar. The fermionic component is assumed to have a global $\mathrm{U(1)_{DM}}$ and interacts with the pseudo scalar via Yukawa interaction while a Z_2 symmetry is imposed on the other component the scalar. These ensure the stability of both the dark matter components. Although the Lagrangian of the present model is CP conserving, however the CP symmetry breaks spontaneously when the pseudo scalar acquires a vacuum expectation value (VEV). The scalar component of the dark matter in the present model also develops a VEV on spontaneous breaking of the Z_2 symmetry. Thus the various interactions of the dark sector and the SM sector are progressed through the mixing of the SM like Higgs boson, the pseudo scalar Higgs like boson and the singlet scalar boson. We show that the observed gamma ray excess from the Galactic Centre, self-interaction of dark matter from colliding clusters as well as the 3.55 keV X-ray line from Perseus, Andromeda etc. can be simultaneously explained in the present two component dark matter model

- We explore the idea of an alternative framework for particle dark matter candidate known as Feebly Interacting Massive Particle (FIMP) with a two component singlet scalar model. Singlet scalar(s) dark matter has already been demonstrated in literature to be a viable candidate for WIMP dark matter. But here we pursue a two component scalar dark matter model in FIMP scenario. In FIMP framework, dark matter particles are slowly produced via "thermal freeze-in" mechanism in the early Universe and are never abundant enough to reach thermal equilibrium or undergo pair annihilation inside the Universe's plasma due to their extremely small coupling. We demonstrate that for smaller couplings too, required for freeze-in process, the present two component scalar dark matter model could well be a viable candidate for FIMP.

6.5 Dark Energy models and phenomenology

- From the analysis of Supernova Ia data along with Observational Hubble Data (OHD) and Baryon Acoustic Oscillation (BAO) data, we attempt to find out the nature of a scalar potential that may be responsible for the Dark Energy of the universe. We demonstrate that in order to explain the varying dark energy equation of state ($\omega_X(z)$) as obtained in a model independent way from the analyses of observational data, we need to invoke a quintom scalar field having a quintessence part for $\omega_X(z) > 1$ and a phantom part for

$\omega_X(z) < 1$. We consider a Gaussian type potential for these scalar fields and compare the dark energy equation of state derived from such potential with the one computed from the data analysis.

- We propose a two parameter generalization for the dark energy equation of state w_X (EOS) for thawing dark energy models which includes PNGB, CPL and Algebraic thawing models as limiting cases; and confront our model with latest Supernova Type Ia (SNe Ia) Data from Union 2.1 compilation, latest Observational Hubble Data (OHD), Cosmic Microwave Background (CMB) Data from 9 year WMAP results and latest BOSS data from SDSS-III Baryon Oscillation Spectroscopic Survey to constrain our parameters space. The best-fit results of our analysis reveal that the phantom type of thawing dark energy is more favoured than the quintessence and both are unequally (phantom is more) favoured upto 2σ confidence level. Moreover the results show that the thawing dark energy EOS is not unique from the observational point of view so far as the dark energy EOS, statefinder pair $\{r,\ s\}$ and $Om3$ parameters are concerned. But the different thawing dark energy models are not distinguishable from each other with the help of best-fit values of matter density parameter at present epoch, present epoch value of hubble parameter (and upto their 2σ C.L.s), best-fit plots of linear growth of matter perturbation and the average deceleration parameter plots. Only effect of different thawing models obtained by tuning the model parameters (present in the proposed generalization for thawing dark energy EOS) is visible in the best-fit variations (with the scale factor a of the universe) of thawing dark energy EOS, the model-independent geometrical diagnostics like the statefinder pair $\{r,\ s\}$ and $Om3$ parameter. We are thus led to the conclusion that unlike the standard observables (matter density parameter, hubble parameter at the present epoch, growth factor evolution and average deceleration parameter evolution), the model-independent parameters $(r,\ s,\ Om3)$ and the variation of EOS (in terms of $w_X - w'_X$ plot) serve as model discriminators for different thawing dark energy models.

- We examine the cosmological viability of a slow moving galileon field in a potential. The Lagrangian $\mathcal{L} = -\frac{1}{2}g^{\mu\nu}\pi_{;\mu}\pi_{;\nu} + \frac{G^{\mu\nu}}{2M^2}\pi_{;\mu}\pi_{;\nu}$ respects the galileon symmetry in curved space time. We carry out detailed investigations of the underlying dynamics of this Lagrangian with Einstein-Hilbert term and a potential. We demonstrate that the model can give rise to a viable ghost free late time acceleration of universe. Furthermore we study the cosmological perturbation of the model and see that the model gives different BBN constraints at early times. We also carry out the observational analysis of the model and use observational data from growth, Type Ia Supernovae (SNIa), Baryon Acoustic Oscillations (BAO) and Cosmic Microwave Background (CMB) to constrain the parameters of the theory.

6.6 Neutrinos

6.6.1 Supernova neutrino detection

- **Detecting supernova neutrinos with lead and iron detectors :**
  Supernova (SN) neutrinos can excite the nuclei of various detector materials beyond their neutron emission thresholds through charged current (CC) and neutral current (NC) interactions. The emitted neutrons, if detected, can be a signal for the supernova event. In this work a comparative study of SN neutrino detection through the neutron channel in detectors made of lead (^{206}Pb) and iron (^{56}Fe) has been done for realistic neutrino fluxes and energies given by the recent Basel/Darmstadt simulations for a 18 solar mass progenitor SN at a distance of 10 kpc. It is pointed out that although the total number of neutrons produced per kTon of iron is more than an order of magnitude lower than that for lead, the dominance of the flavor blind NC events in the case of iron, as opposed to dominance of ν_e induced CC events in the case of lead, offers a complementarity between the two detector materials so that simultaneous detection of SN neutrinos in a lead and a sufficiently large iron detector (for example the proposed 50 kTon ICAL detector planned to be located at the proposed India-based Neutrino Observatory (INO)) suitably instrumented for neutron detection may allow estimating the fraction of the total μ and τ flavored neutrinos in the SN neutrino flux and thereby probing the emission mechanism as well as flavor oscillation scenarios of the SN neutrinos. [A. Bandyopadhyay, P. Bhattacharjee, S. Chakraborty, K. Kar, and S. Saha, *Phys. Rev. D* **95**, 065022 (2017)].

- **Observing supernova neutrino "light curve" in future dark matter detectors using coherent neutrino-nucleus elastic scattering :**
  It is pointed out that future 1-ton class low threshold ($\lesssim 1\,\text{keV}$) Xenon detectors for Dark Matter should be able to detect the "light curve" (arrival time profile) of neutrinos from a Galactic supernova at a distance of $\lesssim$ 10 kpc through the process of coherent neutrino-nucleus elastic scattering. Further, larger detectors may be able to identify the neutrinos associated with different phases (neutronization burst phase, accretion phase, and so forth) of the supernova explosion. [S. Chakraborty, P. Bhattacharjee and K. Kar, *Phys. Rev. D* **89** (2014) 013011].

6.6.2 Neutrino Oscillation Physics

- It is now established that neutrinos exhibit the phenomenon of oscillation whereby one type of neutrino (electron, muon or tau) can change to another flavour when they propagate through vacuum or matter. It is also established that they are massive and the fact that their mass eigenstates and their weak interaction eigenstates are not same explain the phenomenon of oscillation.

  Such oscillations can also be initiated if three different neutrinos have different velocities. In this scenario the rotation between the flavour and velocity eigenstates can induce neutrino flavour oscillation. But these effects are found to be too small to be probed by terrestrial neutrino experiments. We also consider three types of neutrinos having different velocities such that the velocity eigenstates differ from flavour eigenstates and mass eigenstates. We consider a three flavour scenario with velocity oscillation and write down the oscillation probabilities. both in the vacuum case and including matter (MSW) effect. In this scenario, the oscillation depends on the difference of velocities ΔV of two different neutrinos. We also explore the possible magnitudes for ΔV in order that this velocity driven oscillation can have significant effects in the combined oscillation scenario mentioned above. We then applied our formalism to estimate the possible muon yields in a Long baseline neutrino experiment in case, the proposed India-based Neutrino Observatory (INO) detects the neutrinos in a neutrino beam (containing ν_μ and $\bar{\nu}_e$) from a proposed neutrino factory at CERN (CERN - INO baseline length $\sim$ 7100 Km). In such a scenario INO would detect them in the disappearance channel (disappearance or depletion of ν_μ in the beam due to its oscillation in the baseline) and in appearance channel (appearance of $\bar{\nu}_\mu$ due to $\bar{\nu}_e \longrightarrow \bar{\nu}_\mu$ oscillation).

- We calculate the oscillation probability of ultra high energy neutrinos from Gamma Ray Bursts (GRBs) in a 4-neutrino oscillation scenario where an extra sterile neutrino is considered along with the usual 3 flavour scenario. The flux of such neutrinos on reaching the earth is then computed. The muon flavoured neutrinos in such flux, on entering into earth's matter, will undergo charged current scattering with the rock and produce muons which can be detected by a terrestrial detector. The muon yield from a possible UHE neutrino flux that undergoes a 4-flavour neutrino oscillation is estimated at a square kilometer ice Cherenkov detector such as ICECUBE. A similar calculation is obtained in case of 3-flavour oscillation and comparisons have been made between the two results. These calculations are done both for diffuse neutrino flux from a distribution of GRBs as also from a particular GRB at a redshift z from the earth.

6.6.3 Neutrino Mass matrix phenomenology, Baryogenesis through Leptogenesis

- Within the type-I seesaw and in the basis where charged lepton and heavy neutrino mass matrices are real and diagonal, $\mu\tau$ symmetric four and three zero neutrino Yukawa textures are perturbed by lowest order $\mu\tau$ symmetry breaking terms. These perturbations are taken to be the *most general ones for those textures.* For quite small values of those symmetry breaking parameters, permitting a lowest order analysis, current best-fit ranges of neutrino mass squared differences and mixing angles are shown to be accommodable, including a value of θ_{13} in the observed range, provided all the light neutrinos have an inverted mass ordering.

- General Majorana neutrino mass matrix is complex symmetric which has 12 real parameters. All physical observables in this mass matrix are obtained in terms of parameters of the mass matrix elements. The three neutrino masses, three mixing angles, one Dirac CP phase and two Majorana phases (removing three unphysical phases) are explicitly calculated. We apply the result in the context of broken cyclic symmetric neutrino mass matrix invoking type-I seesaw mechanism. The symmetry invariant mass matrix is incapable to satisfy extant data due to degeneracy of two eigenvalues. Symmetry is broken in the right handed neutrino sector in the most general way by two symmetry breaking parameters. We have seen that 10% breaking of this symmetry is sufficient to accommodate all neutrino oscillation experimental data. In this model normal mass hierarchy is preferred and inverted hierarchy is ruled out. In addition we have numerically estimated the Dirac CP phase and Majorana phases. Σm_i and $|m_{\nu_{ee}}|$ are also calculated and they are within the experimental bound.

- The inverse neutrino seesaw, characterized by only one source of lepton number violation at an ultralight O(keV) scale and observable new phenomena at TeV energies accessible to the LHC, is considered. Maximal zero textures of the 3×3 lighter and heavier Dirac mass matrices of neutral leptons, appearing in the Lagrangian for such an inverse seesaw, are studied within the framework of $\mu\tau$ symmetry in a specified weak basis. That symmetry ensures the identity of the positions of maximal zeros of the heavy neutrino mass matrix and its inverse. It then suffices to study the maximal zeros of the lighter Dirac mass matrix and those of the inverse of the heavier one since they come in a product. The observed absence of any unmixed neutrino flavour and the assumption of no strictly massless physical neutrino state allow only eight 4-zero $\times$ 4-zero, eight 4-zero $\times$ 6-zero and eight 6-zero $\times$ 4-zero combinations. The additional requirement of leptogenesis is shown to eliminate the last sixteen textures. The surviving eight 4-zero $\times$ 4-zero textures are subjected to the most general explicit $\mu\tau$ symmetry breaking terms in the Lagrangian in order to accommodate the nonzero value of θ_{13} in the observed range. A full diagonalisation is then carried out. On numerical comparison with all extant and relevant neutrino (antineutrino) data, seven of these eight combination textures in five neutrino matrix forms are found to be allowed, leading to five distinct neutrino mass matrices. Two of these permit only a normal (and the other three only an inverted) mass ordering of the light neutrinos.

- Baryogenesis via Leptogenesis is studied in detail in an $SU(2)_L \times U(1)_Y$ model invoking three right handed neutrino and cyclic permutation symmetry. First, we have restricted the parameter space utilizing neutrino oscillation data, Planck experimental bound on the sum of the three neutrino masses and neutrinoless double beta decay experimental bound on $m_{\nu_{ee}}$. Further, we utilize the parameter space to satisfy the net baryon asymmetry $\eta_B > 0$. We explore three types of leptogenesis flavored, unflavored and fully flavored in different energy regime. At present we are preparing the draft of the manuscript.

- We investigate scaling ansatz with texture zeros within the framework of linear seesaw mechanism. In this variant of seesaw mechanism a simplified expression of effective neutrino mass matrix m_ν containing two Dirac type matrices (m_D and m_{DS}) and one Majorana type matrix (m_{RS}) is obtained by virtue of neglecting the global $U(1)_L$ symmetry breaking term in the mass term of the Lagrangian. Along with the charged lepton mass matrix, the matrix m_{RS}, too, is chosen in a diagonal basis whereas a scaling relation is incorporated in m_D and m_{DS} with different scale factors. Our goal in this work is to achieve a complete phenomenologically acceptable m_ν generated by combinations of m_D and m_{DS} containing least number of independent parameters or maximum number of zeros. At the end of the numerical analysis it is found that number of zeros in any of the constituent Dirac type matrices (m_D and m_{DS}) of m_ν cannot be greater than six in order to meet the phenomenological requirements. The hierarchy obtained here is normal and also the values of the two parameters, sum mass (Σm_i) and $|m_{\nu_{ee}}|$, are below the present experimental lower limit.

- We investigate neutrino mass matrix phenomenology involving scaling ansatz and texture zeros adhering inverse seesaw mechanism. It is seen that four is the maximum number of zeros in m_D and μ to obtain viable phenomenology. Depending upon the generic nature of the effective neutrino mass matrices we classify all the emerged matrices in four categories. One of them is ruled out phenomenologically due to inappropriate value of reactor mixing angle after breaking of the scaling ansatz. The mass ordering is inverted in all cases. One of the distinguishable feature of all these categories is the vanishingly small value of CP violation measure J_{CP} due to small value of δ_{CP} . Thus those categories will be ruled out if CP violation is observed in the leptonic sector in future experiments.

- We estimate the Majorana phases for a general 3×3 complex symmetric neutrino mass matrix on the basis of Mohapatra-Rodejohann's phase convention using the three rephasing invariant quantities I_{12}, I_{13} and I_{23} constructed out of the mass matrix elements. Such a model independent approach allows us to evaluate each Majorana phase even if one eigenvalue is zero. Utilizing the solution of a general complex symmetric mass matrix for eigenvalues and mixing angles we determine the Majorana phases for both the hierarchies, normal and inverted, taking into account the constraints from neutrino oscillation global fit data as well as bound on the sum of the three light neutrino masses. The allowed ranges of the Majorana phases (α, $\beta+\delta$) are obtained as $78^o < \alpha < 77.5^o$, $47^o < \beta+\delta < 46.8^o$ for normal hierarchy and $41.4^o < \alpha < 41.8^o$, $54.2^o < \beta+\delta < 53.2^o$ for inverted hierarchy. This generalized methodology of finding the Majorana phases is applied thereafter in some typical models for both the hierarchical cases to evaluate the corresponding Majorana phases.

- Baryogenesis via leptogenesis is investigated in a specific model of light neutrino masses and mixing angles. The latter was proposed on the basis of an assumed complex-extended scaling property of the neutrino Majorana mass matrix M_ν, derived with a type-1 seesaw from a Dirac mass matrix m_D and a heavy singlet neutrino Majorana mass matrix M_R. One of its important features, highlighted here, is that there is a common source of the origin of a nonzero θ_{13} and the CP violating lepton asymmetry through the imaginary part of m_D. The model predicted CP violation to be maximal for the Dirac type and vanishing for the Majorana type. We assume strongly hierarchical mass eigenvalues for M_R. The leptonic CP asymmetry parameter $\epsilon_{\alpha 1}$ with lepton flavor α, originating from the decays of the lightest of the heavy neutrinos N_1 (of mass M1) at a temperature TM_1, is what matters here with $\epsilon_{\alpha_{2,3}}$, originating from the decays of $N_{2,3}$ being washed out. The light leptonic and heavy neutrino number densities (normalized to the entropy density) are evolved via Boltzmann equations down to electroweak temperatures to yield a baryon asymmetry through sphaleronic transitions. The effect of flavored vs. unflavored leptogenesis in the three mass regimes (1) $M_1 < 10^9$ GeV, (2) 10^9 GeV $< M_1 < 10^{12}$ GeV and (3) $M_1 > 10^{12}$ GeV are numerically worked out for both a normal and an inverted mass ordering of the light neutrinos. Corresponding results on the baryon asymmetry of the universe are obtained, displayed and discussed.

- The residual symmetry approach, along with a complex extension for some flavor invariance, is a powerful tool to uncover the flavor structure of the 3×3 neutrino Majorana mass matrix M_ν towards gaining insights into neutrino mixing. We utilize this to propose a complex extension of the real scaling ansatz for M_ν which was introduced some years ago. Unlike the latter, our proposal allows a nonzero mass for each of the three light neutrinos as well as a nonvanishing θ_{13}. A major result of this scheme is that leptonic Dirac CP-violation must be maximal while atmospheric neutrino mixing need not be exactly maximal. Moreover, each of the two allowed Majorana phases, to be probed by the search for nuclear $0\nu\beta\beta$ decay, has to be at one of its two CP-conserving values. There are other interesting consequences such as the allowed occurrence of a normal mass ordering which is not favored by the real scaling ansatz. Our predictions will be tested in ongoing and future neutrino oscillation experiments at T2K, $NO\nu A$ and DUNE.

- We investigate Linear and Inverse seesaw mechanisms with maximal zero textures of the constituent matrices subjected to the assumption of non-zero eigenvalues for the neutrino mass matrix m_ν and charged lepton mass matrix m_e. If we restrict to the minimally parametrized non-singular m_e (i.e., with maximum number of zeros) it gives rise to only 6 possible textures of m_e. Non-zero determinant of m_ν dictates six possible textures of the constituent matrices. We ask in this minimalistic approach, what are the phenomenologically allowed maximum zero textures are possible. It turns out that Inverse seesaw leads to 7 allowed two-zero textures while the Linear seesaw leads to only one. In Inverse seesaw, we show that 2 is the maximum number of independent zeros that can be inserted into μ_S to obtain all 7 viable two-zero textures of m. On the other hand, in Linear seesaw mechanism, the minimal scheme allows maximum 5 zeros to be accommodated in μ so as to obtain viable effective neutrino mass matrices ($m\nu$). Interestingly, we find that our minimalistic approach in Inverse seesaw leads to a realization of all the phenomenologically allowed two-zero textures whereas in Linear seesaw only one such texture is viable. Next our numerical analysis shows that none of the two-zero textures give rise to enough CP violation or significant δ_{CP}. Therefore, if $\delta_{CP} = \pi/2$ is established, our minimalistic scheme may still be viable provided we allow more number of parameters in m_e.

- Within the framework of inverse seesaw mechanism we investigate neutrino mass matrices invariant under cyclic symmetry (Z_3) with maximal zero texture (6 zero textures). We explore two different approaches to obtain the cyclic symmetry invariant form of the constituent matrices. In the first one we consider explicit cyclic symmetry in the neutrino sector of the Lagrangian which dictates the emerged effective neutrino mass matrix (m_ν) to be symmetry invariant and hence leads to a degeneracy in masses. We then consider explicit breaking of the symmetry through a dimensionless parameter ϵ to remove the degeneracy. It is seen that the method doesn't support the current neutrino oscillation global fit data even after considering the correction from cyclic symmetry invariant charged lepton mass matrix (m_l) unless the breaking parameter is too large. In the second method, we assume the same forms of the neutrino mass matrices, however, symmetry is broken in the charged lepton sector. All the structures of the mass matrices are now dictated by an effective residual symmetry of some larger symmetry group in the Lagrangian. For illustration, we exemplify a toy model based on softly broken A_4 symmetry group which leads to one of the combination of m_l, m_D, M_{RS} and μ to generate effective m_ν. All the emerged mass matrices predict a constraint range of the CP violating phases and atmospheric mixing angle along with an inverted hierarchical structure of the neutrino masses. Further, significant predictions on $\beta\beta0\nu$ decay parameter —m_{11}— and the sum of the three light neutrino masses ($\Sigma_i m_i$) are also obtained.

6.7 Core Collapse Supernovae and Neutron Stars

- We constructed new hyperon equation of state (EoS) tables for core-collapse supernova simulations and neutron stars. These EoS tables are based on a density-dependent relativistic hadron field theory where baryon-baryon interaction is mediated by mesons, using the DD2 parameter set for nucleons. Furthermore, light and heavy nuclei along with the interacting nucleons are treated in the nuclear statistical equilibrium model of Hempel and Schaffner-Bielich which includes excluded volume effects. Of all possible hyperons, we consider only the contribution of lambda hyperons. We developed two variants of hyperonic EoS tables: in one case case the repulsive hyperon-hyperon interaction mediated by the strange phi meson is taken into account, and in the other case it is not. The EoS tables for the two cases encompass wide range of densities, temperatures, and proton fractions. These are known as BHB (Banik, Hempel and Bandyopadhyay) EoS tables. The effects of lambda hyperons on thermodynamic quantities such as free energy per baryon, pressure, or entropy per baryon are investigated and found to be significant at higher densities. These hyperon EoS tables are publicly available for core collapse supernova and neutron star merger simulations from the Caltech Supernova Group's website (stellarcollapse.org) and European website CompactStar Online Supernovae Equations of State (CompOse). [S. Banik, M. Hempel and D. Bandyopadhyay, ApJS 214 (2014) 22]

- The role of lambda hyperons on supernova explosion mechanism and the evolution of protoneutron star (PNS) was studied using a general relativistic one dimensional core collapse supernova model. The lambda hyperon equation of state (EoS) of Banik, Hempel and Bandyopadhyay was used as microphysical input in these simulations. This investigation involving an exotic matter EoS which is compatible with 2 solar mass neutron stars, is the first of its kind. It was demonstrated that lambda hyperons appeared just after core bounce and its population became significant as the PNS evolved. The PNS collapsed to a black hole due to mass accretion. Furthermore, the long duration evolution of the PNS with enhanced neutrino heating in the supernova simulation with 20 solar mass progenitor was studied. This led to a successful supernova explosion and the PNS evolved to a stable neutron star at the end of 4 sec. The implications of those findings were discussed in the light of no show of a neutron star in SN1987A. [P. Char, S. Banik and D. Bandyopadhyay, ApJ 809 (2015) 116]

- The slowly rotating general relativistic superfluid neutron stars including the entrainment effect are investigated in a two-fluid model, where one fluid represents the superfluid neutrons and the other is the charge-neutral fluid, called the proton fluid, made of protons and electrons. The equation of state and the entrainment effect between the superfluid neutrons and the proton fluid are computed using a relativistic mean field model (RMF) where baryon-baryon interaction is mediated by the exchange of scalar and vector mesons, and scalar self-interactions are also included. The equations governing rotating neutron stars in the slow rotation approximation are second order in rotational velocities of neutron and proton fluids. We explore the effects of the isospin dependent entrainment and the relative rotation between two fluids on the global properties of rotating superfluid neutron stars such as mass, shape, and the mass-shedding (Kepler) limit within the RMF model with different parameter sets. It is observed that the global properties of rotating superfluid neutron stars are modified compared with the case that does not include the contribution of isospin in the entrainment effect. [A. Kheto and D. Bandyopadhyay, Phys. Rev. D91 (2015) 043006 and Phys. Rev D89 (2014) 023007]

- Strong magnetic fields have important effects on the crustal properties of magnetars. The magneto-elastic oscillations of magnetars are studied taking the effect of strong magnetic fields on the crustal composition (magnetized crust), into consideration. We calculate global magneto-elastic (GME) modes as well as modes confined to the crust (CME) only. The ideal magneto hydrodynamics is adopted for the calculation of magneto-elastic oscillations of magnetars with dipole magnetic fields. The perturbation equations obtained in general relativity using Cowling approximation are exploited here for the study of magneto-elastic oscillations. Furthermore, deformations due to magnetic fields and rotations are neglected in the construction of equilibrium models for magnetars. The composition of the crust directly affects its shear modulus which we calculate using three different nucleon-nucleon interactions: SLy4, SkM and Sk272. The shear modulus of the crust is found to be enhanced in strong magnetic fields $\geq 10^{17}$ G for all those Skyrme interactions. It is noted that the shear modulus of the crust for the SLy4 interaction is much higher than those of the SkM and Sk272 interactions in presence of magnetic fields or not. Though we do not find any appreciable change in frequencies of fundamental GME and CME modes with and without magnetized crusts, frequencies of first overtones of CME modes are significantly affected in strong magnetic fields $\geq 10^{17}$ G. [R. Nandi, P. Char, D. Chatterjee and D. Bandyopadhyay, Phys. Rev. C94 (2016) 025801]

- Rotating bodies in General Relativity produce frame dragging, also known as the Gravitomagnetic effect in analogy with Classical Electromagnetism. In this work, we studied the effect of magnetic fields in neutron stars on the Gravitomagnetic effect, which is produced as a result of its rotation. We showed that the magnetic field had a non-negligible impact on the frame dragging. The maximum effect of the magnetic field appeared along the polar direction, where the frame-dragging frequency decreased with increase in magnetic field, and along the equatorial direction, its magnitude increased. For intermediate angles, the effect of the magnetic field decreased, and passed through a minimum for a particular angular value at which magnetic field had no effect on Gravitomagnetism. Beyond that particular angle Gravitomagnetic effect increased with increasing magnetic field. We explored this "Null Region" for the case of magnetized neutron stars, both inside and outside, as a function of the magnetic field. We demonstrated how to find the null region of a particular pulsar using the frame dragging effect in a pulsar-planet binary system. [D. Chatterjee, C. Chakraborty and D. Bandyopadhyay, JCAP 1701 (2017) 062]

6.8 Workshop/School/Conference organized by APC Division

- XXVII Main School on Theoretical High Energy Physics at SINP, Sep. 03 - 23, 2012, School Director - **Debasish Majumdar**

- Workshop on "Neutron Stars: Inside and Outside", October 18-19, 2012, Organized by **Debades Bandyopadhyay**/Sarmistha Banik.

- 1st International Conference on Advances in Astroparticle Physics and Cosmology (AAPCOS 2012), Darjeeling, Mar 07 - 12, 2012, Convenor - **Debasish Majumdar**.

- 2nd International Conference on Advances in Astroparticle Physics and Cosmology (AAPCOS 2013), Institute for Advances Studies, Shimla, June 14- 17, 2013, Convenor - **Pratik Majumdar**.

- International Conference on Advances in Astroparticle Physics and Cosmology (AAPCOS 2015), October 12 - 17, 2015. Convenor - **Debasish Majumdar**.

- Outreach Programme on Different Aspects of Astroparticle Physics and Cosmology, October 13, 2015 (Part of AAPCOS 2015). **Debades Bandyopadhyay/Debasish Majumdar**

- Lecture Course on Astroparticle Physics, October 12-13, 2015 (Part of AAPCOS 2015), Organized by **Mala Das/Debasish Majumdar**.

Note: AAPCOS is a unique international conference series in India that is dedicated to the discussions and developments only in the field of Astroparticle Physics which is initiated and organized by APC Division of SINP.

6.9 Invited talks/colloquia/Seminars delivered by Division members during this period

Pijushpani Bhattacharjee

- "Mass Discrepancy in Rotating Galaxies: Visible-Invisible Conspiracy, MOND, and all that"
— Invited talk at the *Candles of Darkness* (CANDARK-2017) Symposium, ICTS-TIFR, Bengaluru, 5–9 June 2017.

- "On the Trail of WIMPs: Detecting the Weakly Interacting Massive Particle Candidates of Dark Matter"
— Invited talk at the National Conference on *Frontiers of Physics*, University of Burdwan, Burdwan, 30–31 March 2017,

- "Whither WIMP Dark Matter Search?"
–Invited Plenary talk at *International Conference on Gravitation & Cosmology (ICGC-2015)*, IISER-Mohali, 14–18 December 2015.

- "Darkness Abound: Is there hope?"
— Invited Evening talk at *CNT QGP Meet 2015*, VECC, Kolkata, 16–20 November 2015.

- "Direct detection of WIMP Dark Matter"
— Invited talk at *Topical Conference on Gravity and Cosmology (TCGC)*, Presidency University, Kolkata, 9 August 2014.

- “Direct detection of WIMP Dark Matter”
  — Invited talk *Current Trends in Particle Physics Research* (CTPPR2014), Kalyani University, 13–15 March 2014.

- “Astroparticle Physics – Dark Matter and its detection”
  — A set of three invited pedagogical lectures at the Instructional Workshop ”SANGAM@HRI-2014”, Harish-Chandra Research Institute (HRI), Allahabad, 24-29 March 2014.

- “Dark Matter in the Galaxy: Direct detection of WIMPs”
  — Invited talk at *Workshop on Contemporary Trends in High Energy Physics & Experimentation*, Punjab University, Chandigarh, 10–11 March 2014.

- “Rotation curve and the velocity distribution of the Milky Way’s dark matter particles”
  — Invited seminar at the McDonnel Center for the Space Sciences, Washington University, St. Louis, MO, USA, 1 November 2013.

- “Phase space distribution of dark matter particles in the Galaxy: Implications for direct and indirect detection”
  — Invited talk (delivered on “skype”) at *“SUSY-DM” Workshop*, Centre for High Energy physics (CHEP), IISc., Bangalore, 3–5 October 2013.

- “Dark Matter in the Galaxy: Rotation curve and the phase space distribution of Milky Way’s dark matter particles”
  — Invited Seminar at the Mitchell Institute for Fundamental Physics, Texas A&M University, College Station, Texas, USA, 19 September 2013.

- “Direct detection of Dark Matter”
  — Invited talk at *Advances in Astroparticle Physics & Cosmology (AAPCOS-2013)*, Shimla, India, 14–17 June 2013.

- “Chasing the WIMPs of Milky Way : Direct and Indirect Searches for Dark Matter”
  — Invited talk at the *Victor Hess Symposium*, on the occasion of Centenary of discovery of Cosmic Rays by Victor Hess, Bose Institute, Kolkata, 17 Sept. 2012.

- “Chasing the WIMPs of Milky Way: Direct and Indirect Detection of Dark Matter”
  – Invited Colloquium at *Physical Research Laboratory (PRL), Ahmedabad*, 15 February 2012.

- “Status of the DINO (Dark matter@INO) proposal”
  – Invited talk at *INO Collaboration Meeting*, BARC, Mumbai, 14 February 2012.

Debades Bandyopadhyay

- “Neutron Stars: Exploring role of nuclear physics”, Invited talk in the conference on ”Discoveries at the Frontiers of Science”, Frankfurt Institute for Advanced Studies, Germany, from 26-30 June, 2017
- “Neutron Stars: unique laboratories for fundamental physics at supranuclear densities”, Invited talk in the ”First Asia SKA Initiative on NS (ASIONS)” meeting, Goa, from 4-5 November, 2016
- “Probing neutron star interior with the SKA”, Invited talk in “Neutron Stars: A pathfinder workshop”, NCRA-TIFR, Pune from 14-15 January, 2016.
- ”Exploring many facets of core collapse supernovas”, Colloquium at Saha Institute of Nuclear Physics on 16 October, 2015.
- ”Black hole formation in failed core collapse supernova simulations with hyperon equations of state”, Seminar at Frankfurt Institute for Advanced Studies, Germany on 23 June, 2015
- “Core Collapse supernova simulations with a new hyperon equation of state compatible with two solar mass neutron star”, Talk in the ”Annual NewCompStar Conference 2015”, Budapest, Hungary from 15-19 June, 2015
- “Supernova Explosions: The role of hyperon matter”, Plenary talk in the 59th DAE-BRNS Nuclear Physics Symposium, Benaras Hindu University (BHU), Varanasi on 11 December, 2014
- “Exploring many facets of core collapse supernovae and neutron stars”, Invited talk in the ”Sixth Asian Nuclear Physics Association Symposium” at Variable Energy Cyclotron Centre, Kolkata from 19-21 February, 2014.
- “Role of magnetized crust on torsional shear mode oscillations”, Invited talk in the workshop ”Neutron rich matter and neutron stars” at ECT*, Trento, Italy on 3 October, 2013

Pratik Majumdar

- *Cosmic Rays : An Experimental Perspective (Invited Review Talk)* XX DAE-BRNS High Energy Physics Symposium, Shantiniketan, January 2013
- *Very High Energy Gamma ray Astronomy : A tool to Study the High Energy Universe (Invited Review Talk)*
  IAGRG, Hemwati Nandan Bahuguna University, Garhwal, March 2013
- *Recent Highlights from the VERITAS Experiment (Contributory Talk)*
  International conference TeV Particle Astrophysics (TeVPA),
  TIFR, Mumbai, December, 2012
- *Cosmic Rays : An Experimental Perspective (Invited Review Talk)* XX DAE-BRNS High Energy Physics Symposium, Shantiniketan, January 2, 2013
- *Origin of Cosmic Rays: A 100 Year Old Story (Invited Review Talk)*
  Recent trends in Condensed Matter and High Energy Physics (RCHP) held at IACS, Kolkata from Jan 30th to Feb 1st, 2017
- Colloquium on *The Universe Viewed in Very High Energy Gamma Rays : Present Status and Future Directions* delivered at NCRA, TIFR (28th April, 2014)
- Colloquium on *Exploring the Universe with High Energy Particles and Photons* delivered at Presidency University, Kolkata (14th January, 2015)
- Astronomy Seminar on *Exploring the Universe in TeV gamma-rays* delivered at IISc, Bangalore (24th November, 2015)
- Free Meson Seminar on *Origin of Cosmic Rays through the eyes of TeV gamma-rays* delivered at TIFR, Mumbai (26th November, 2015)
- Lectures on *Exploring the Universe with Particles and Photons* delivered at DST-INSPIRE Camp, IISER, Pune (20th July, 2016)
- Public Lecture on *Guest Stars of the Universe* delivered to INSPIRE School students at JBNSTS, Kolkata (December 2016)

Debasish Majumdar

- Physical Research Laboratory, Ahmedabad, India on **Scalar Singlet Dark Matter** as *TPSC* speaker, July, 2012.
- A lecture on Dark Matter at S.S. College, Hailakandi, Assam
- Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi, India on **Two Component Dark Matter, an explanation of 130 GeV gamma line from galactic Centre** April, 2013 (invited talk).
- Department of Physics, Panjab University, Chandigarh on **Dark Matter: evidence and detection** in May 2013 (invited talk).
- Department of Physics, Kashmir University, Srinagar, on **Dark Matter** in May 2013.
- Department of Physics, University of Kalyani, at "Current Trends in Particle Physics Research", invited talk on **Neutrino Physics**.
- "International Workshop on Unification and Cosmology after Higgs Discovery (UNICOS2014) held at Department of Physics, Panjab University, Chandigarh during 13 - 15 May, 2014 and delivered an invited talk on Dark Matter Explanation of Gamma emission from Galactic Centre and Fermi Bubble region.
- "Invisible matters: Neutrino and dark matter" at Indian Institute of Technology, Hyderabad, India in October, 2014. Delivered an invited lecture on Nonthermal Two Component Dark Matter
- "Dark Side of the Universe" held at "Center for Astrophysics Cosmology and Gravity, University of Cape Town" at South Africa,
- "Exploring the Cosmos" held at North Bengal University, Siliguri on January 22, 2015 and delivered an invited talk on Generalizing Thawing Dark Energy Models.
- "LHC and Dark Matter" (LHCDM 2015) at Indian Association for the Cultivation of Science (IACS), Kolkata during the period February 16 - February 20, 2015 and delivered an invited talk.
- "Topical Conference on Gravity and Cosmology (Eastern Region)" (TCGC (ER)) at Indian Institute of Technology, Kharagpur on February 28, 2015 and delivered a lecture on Late Time Acceleration in a Slow Moving Galileon Field.

- Workshop on "Light from dark side of the Universe" during 17th - 20th March 2015 at Department of Physics, Banaras Hindu University, Varanasi and delivered an invited talk on Dark Matter.
- "DAE-BRNS Symposium on Nuclear Physics" at Puttapurthy, A.P., December, 2015. Invited speaker. Invited talk on Dark Matter delivered.
- Invited Lecture at WAPP (Winter Workshop on Astroparticle Physics), Bose Institute, Darjeeling, December, 2015.
- Invited talk at PHENO1IISERM, April 06 - 09, 2016, IISER, Mohali.
- Invited talk at the Ino-US workshop "Invisible Sector: Neutrinos and Dark matter" at University of Hyderabad, Hyderabad (Nov. 16 - 18, 2016).
- Invited mini-review talk on Dark Matter at XXII DAE-BRNS High Energy Physics Symposium at University of Delhi, Delhi, Dec. 12-16, 2016.
- Invited talk at "National Workshop on Recent Advances in Astrophysics and Cosmology" during March 17-18, 2017 at Department of Physics, University of North Bengal, Siliguri.

6.10 Teaching by Division Members

Pijushpani Bhattacharjee

- **High Energy Astrophysics & Astroparticle Physics**
  — Post-M.Sc course at SINP, Jan–March 2012.
- **Advances in High Energy & Astroparticle Physics**
  — Post-M.Sc. course at SINP, Jan–March 2017.

Debasish Majumdar

- A 3-Lecture course on **Dark Matter** in "CNT Lectures on Special Topics on Nuclear Astrophysics" at VECC, Kolkata in March 2017.
- **Dark Matter**, an eight lecture course delivered at "Winter School on Beyond the Standard Model Physics" at Department of Physics, Banaras Hindu University, Varanasi, January, 2016.
- **Introduction to Dark Matter**, A four lecture course given at "National Level School on Gravitation and Astroparticle Physics" at Central University of Himachal Pradesh, Dharamshala in March, 2016.

- **Introduction to Dark Matter**, a series of three lectures delivered at a School on Astroparticle Physics, Bose Institute, Darjeeling Campus, December, 2015.
- **Dark Matter**, a series of two lectures at Department of Physics, Assam University, Silchar, October, 2015.
- A one semester course on Astroparticle Physics to the Post M.Sc. students, Saha Institute of Nuclear Physics (2015-16 batch).
- **Dark Matter** a series of two lectures at Indian Institute of Technology, Indore, April 2014.
- A course on Cosmology and Dark Matter to the Post M.Sc. students, SINP (2014-15 batch)
- A course taken entitled "Astroparticle Physics I" to Post-M.Sc. students at SINP (2016-17 batch).
- A course on "Standard Model Interactions" to the M.Sc. 4th semester students at St. Xavier's College, Kolkata (Jan. - Apr., 2017).

Debades Bandyopadhyay

- "A short course on the physics of neutron stars" at NCRA-TIFR, Pune from 23-29 March, 2017.
- A lecture series on "Neutron Stars: From the crust to the interior" in the pedagogic school under "Neutron Stars: A pathfinder workshop", NCRA-TIFR, Pune from 6-13 January, 2016.
- A course on "Physics of Supernovae and Compact Stars" in the Winter school on "Nuclear Astrophysics" held at VECC, Kolkata from 19-31 January, 2015

Pratik Majumdar

- Post M.Sc. "Post MSc course on Basic Astroparticle Physics" in 2012, 2013 and 2014.

7 Future Directions:

7.1 Dark Matter Search Experiments:

The PICO program currently consists of two major components. The first is the underground physics program with operating chambers which, while collecting valuable physics data are, in parallel, allowing the detector technology to be further refined. The second component is the research and development effort at the laboratories of the collaborating member institutions, where detector calibrations are performed, systematic investigations into detector performance and response are conducted, and the details for the design of the next generation PICO detectors are being developed. The ultimate goal of the collaboration is to build a large scale (ton) low background detector with excellent sensitivity that will probe the available phase space for SD dark matter interactions.

Towards these goals, the PICO collaboration group at SINP, currently being led by Mala Das, seeks continued financial and operational support for the ongoing R&D work, design and fabrication of some components of the detector, shifts operation, simulation and data analysis at SINP for the PICO current and next generation experiment. This will allow the SINP group to effectively contribute in all aspects of the experiment, including operation, calibration, upgradation of the current suite of detectors, extracting the physics results from the data, and designing the next generation detector.

In this context, the main research activities of the SINP group for the PICO experiment will be the following:

- Detector calibration with new low mass target (in order to make the detector specially sensitive to few GeV mass WIMPs),
- detector simulation for different types of backgrounds,
- new generation detector R&D without pressurization system,
- mechanical design and fabrication of camera holding system for viewing the bubble nucleation and the calibration source mounting arrangement for PICO-40/250/500 chamber,
- data analysis of PICO-40/250/500.

The expertise thus developed from this international experiment will also be extremely useful for the recent Indian initiative towards the proposed DINO (DarkMatter@INO) dark matter experiment in India which will use suitable scintillating crystals as the target detector material. PICO being a low threshold experiment primarily covers relatively low-mass WIMP search, and is thus complementary in its goal and techniques to those of the proposed DINO experiment which will probe relatively larger mass WIMPs.

As a possible application of the superheated liquid detector R&D work for the PICO experiment, the SINP group has started collaborating with the Tata Medical Centre (TMC), Kolkata to measure the unwanted neutron dose (this itself being a risk factor for cancer) on cancer patients undergoing radiation therapy whereby the patients are subjected to irradiation with high energy X-rays. The portable superheated liquid detectors for this purpose will be fabricated at SINP. For a different application, the same detectors can also be used for neutron dosimetry studies at different ion accelerator facilities in India.

Finally, in addition to searching for low mass WIMPs, low threshold, large mass (multi-ton), low background superheated liquid detectors can also be used for detecting supernova neutrinos through coherent neutrino-nucleus elastic scattering.

7.2 Extragalactic cosmic Rays and TeV gamma-rays:

- Development of in-house laboratory setup for R&D work towards using silicon photomultipliers (SiPM) as novel devices for TeV gamma-ray astronomy.

- In-kind hardware contributions towards design and construction of calibration systems and SiPM camera for the CTA project.

- Study of origin of galactic and extragalactic cosmic rays with the MAGIC-CTA telescope system and understanding the nature of Extragalactic Background Light (EBL).

- Operations and Maintenance, participation in science runs and upgrades to CTA.

- Multimessenger Astrophysics with synergies between very high energy gamma rays (MAGIC/CTA), X-rays (ASTROSAT), radio waves (GMRT,SKA), optical (HCT,TMT), neutrinos (INO) and gravitational waves (LIGO).

7.3 Neutron Star Physics in the SKA era:

Substantial advancement in the pulsar timing precision is expected to come from the Square Kilometre Array (SKA) . This would lead to the discoveries of large number of relativistic binary pulsar systems or even exotic binary system like pulsar-black hole system. The high precision timing technique in the SKA would determine the moment of inertia of a pulsar earlier than that in the present day scenario. In relativistic binary systems, higher order post Newtonian (PN) effects could be measured. Furthermore, the relativistic spin-orbit (SO) coupling may manifest in an extra advancement of periastron above the PN contributions. The measurement of the SO effect leads to the determination of moment of inertia of a pulsar in the double pulsar system. Neutron star masses have been already estimated to very high degree of accuracy. Observed masses, radii and moments of inertia of neutron stars are direct probes of compositions and EoS in neutron star interior. The theoretical mass-radius, moment of inertia - mass or radius relationships of neutron stars could be directly compared with measured masses, radii and moments of inertia from various observations. Consequently, the composition and equation of state (EoS) of dense matter in neutron stars might be constrained. Another interesting possibility is the presence of superfluidity in neutron star matter. Generally it is inferred that pulsar glitches are the manifestation of superfluid neutron matter in neutron stars. It would be worth investigating the superfluidity in neutron stars in general and the superfluid moment of inertia fraction for pulsar glitches in particular using the precision pulsar timing technique of the SKA.

After the detection of gravitational wave signal from the black hole merger event in GW150914 by the LIGO observatory, gravitational wave astrophysics opens a new window to probe the neutron star interior. This research will be strengthened with the LIGO-India setup in future. We plan to carry out numerical simulations of gravitational waves in the merger of two neutron stars or a neutron star and a black hole which would provide important information about neutron star interior. We are also interested in non-radial oscillations of neutron stars such as r-modes which are important candidates of gravitational wave sources.

7.4 Dark Matter, Dark Energy theory:

- Possible new models for particle dark matter will be explored phenomenologically to explain the possible indirect signatures of dark matter such as the claimed γ-ray excess from Galactic Centre, AMS results for positron fraction excess, etc., as also the recent claims of "evidence" of dark matter self-interaction. The implications of these models for structure formation in the Universe will also be addressed.

- Axions as dark matter candidate will be explored. Also, the effect of possible axion emission from neutron stars will be studied.

- Possible dark matter accretion on massive stars leading to their eventual collapse and consequent gravitational wave emission will be investigated.

- Possible ultra high energy neutrino emission from dark matter annihilation and their possible signals at neutrino detectors such as ICECUBE will be studied.

- The implications of a particular modified gravity theory, namely "slotheon gravity", for explaining the observed accelerated expansion of the Universe and the future fate of the Universe will be studied.

8 List of Publications (Since 2012)

2017:

1. Dark Matter Search Results from the PICO-60 C_3F_8 Bubble Chamber,
   C. Amole et al (PICO Collaboration),
   Phys. Rev. Lett. **118**, 251301 (2017) [arXiv:1702.07666].

2. Detecting supernova neutrinos with iron and lead detectors,
   Abhijit Bandyopadhyay, Pijushpani Bhattacharjee, Sovan Chakraborty, Kamales Kar, Satyajit Saha,
   Phys. Rev. D **95**, 065022 (2017) [arXiv:1607.05591].

3. Final Results of the PICASSO Dark Matter Search Experiment,
   E. Behnke et al (PICASSO collaboration),
   Astropart. Phys. **90**, 85–92 (2017) [arXiv:1611.01499].

4. **Very-high-energy gamma-ray observations of the Type Ia Supernova SN 2014J with the MAGIC telescopes**, Ahnen, M. L et al, accepted for publication in Astronomy & Astrophysics, February (2017)

5. **Long term study of the light curve of PKS 1510-089 in GeV energies**, R.Prince, **P. Majumdar** and N. Gupta, accepted in Astrophysical Journal on 6th June, 2017, arXiv/1706.02133

6. Mala Das, Nilanjan Biswas (2017), "Detection of bubble nucleation event in superheated drop detector by pressure sensor", **Pramana J of Phys.88,** 97-101.

7. **D. Bandyopadhyay**, (2017), "Neutron stars: Laboratories for fundamental physics under extreme astrophysical conditions", Accepted for publication in Journal of Astrophysics and Astronomy.

8. D. Chatterjee, C. Chakraborty, **D. Bandyopadhyay**, (2017), "Gravitomagnetic effect in magnetized neutron stars", JCAP **1701**, 062.

9. S. Bhattacharyya, I. Bombaci, **D. Bandyopadhyay**, A.V. Thampan, D. Logoteta, (2017), "Millisecond radio pulsars with known masses: Parameter values and equation of state models", D. Logoteta, New Astronomy **54**, 61.

10. Rome Samanta, Mainak Chakraborty, Probir Roy, **Ambar Ghosal**, (2017), "Baryon asymmetry via leptogenesis in a neutrino mass model with complex scaling", JCAP **1703**, 025

2016:

1. Long-term study of Mkn 421 with the HAGAR Array of Telescopes,
A. Sinha et al.,
Astron. Astrophys. **591**, A83 (2016) [arXiv:1603.06690].

2. Improved dark matter search results from PICO-2L Run 2,
C. Amole et al. (PICO Collaboration),
Phys. Rev. **D 93**, 061101(R) (2016) (Rapid Communications) [arXiv:1601.03729].

3. Dark matter search results from the PICO-60 CF_3I bubble chamber,
C. Amole et al. (PICO Collaboration),
Phys. Rev. **D 93**, 052014 (2016) [arXiv:1510.07754].

4. **Search for VHE gamma-ray emission from Geminga pulsar and nebula with the MAGIC telescopes** , Ahnen, M. L et al, Astronomy & Astrophysics, Volume 591, id.A138, 7 pp (2016)

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13. **Limits to dark matter annihilation cross-section from a combined analysis of MAGIC and Fermi-LAT observations of dwarf satellite galaxies**, Ahnen, M. L et al, Journal of Cosmology and Astroparticle Physics, Volume 2016, February 2016

14. **MAGIC observations of the February 2014 flare of 1ES 1011+496 and ensuing constraint of the EBL density**, Ahnen, M. L et al, Astronomy & Astrophysics, Volume 590, id.A24, 8 pp (2016)

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8.1 Internal Notes and Technical Reports

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2. **Design of a prototype device to calibrate the Large Size Telescope camera of the Cherenkov Telescope Array**, Iori, M.; **Majumdar, P.**; De Persio, F.; Chatterjee, A.; Ferrarotto, F.; Nagesh, B. K.; Saha, L.; Singh, B. B., Proceedings of the 34th International Cosmic Ray Conference (ICRC2015)

3. **Creating a high-resolution picture of Cygnus with the Cherenkov Telescope Array**, Weinstein, Amanda; Aliu, Ester; Casanova, Sabrina; Di Girolamo, Tristano; Dyrda, Michael; Hahn, Joachim; **Majumdar, Pratik**; Rodriguez, Jerome; Tibaldo, Luigi; for the CTA Consortium, Proceedings of the 34th International Cosmic Ray Conference (ICRC2015)

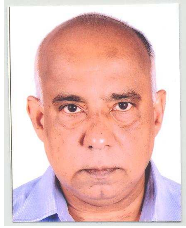
4. **The Camera Calibration Strategy of the Cherenkov Telescope Array**, M. K. Daniel, M. Gaug and **P. Majumdar**; for the CTA Consortium, Proceedings of the 34th International Cosmic Ray Conference (ICRC2015)

5. "Physics Potential of the ICAL detector at the India-based Neutrino Observatory (INO)", ICAL Collaboration (Shakeel Ahmed (Aligarh Muslim U.) et al.), INO-ICAL-PHY-NOTE-2015-01 e-Print: arXiv:1505.07380

8.2 Books/Monographs

1. **Debasish Majumdar**, (2014), **Dark Matter: An Introduction**, CRC Press, Taylor and Francis, 263 pages.

2. "Exploring Fundamental Issues in Nuclear Physics", Edited by **Debades Bandyopadhyay**, 2012, World Scientific, Singapore



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4. **Division:** Astroparticle Physics and Cosmology Division
5. **Academic profile:**

1990	Ph.D. (Sc) degree, SINP and University of Calcutta
Dec. 1991- May 93	Postdoctoral researcher at the Institute for Theoretical Physics, Frankfurt University, Germany.
Sep. 1993- July 97	Visiting Fellow in the Theory Division of SINP.
July 1997	Joined Reader(D) position in the Theory Division of SINP.
August 2001	Promoted to Associate Professor (E) position.
August 2005	Promoted to Professor (F) position.
August 2008	Promoted to Professor (G) position.
May 2010	Joined Astroparticle Physics and Cosmology Division
July 2013	Promoted to Senior Professor (H) position.
July 2016	Promoted to Senior Professor (H+) position.

6. **Fellowships, Awards, honours or distinctions:**

December 1991- May 1993	Alexander von Humboldt Fellowship, Germany.
June 2003 - May 2005	Project based Personnel exchange Programme (PPP) of DST, India - DAAD, Germany.
December 2008- November 2011	Research Group Linkage Programme of Alexander von Humboldt Foundation, Germany.

7. **Essential strength of research/development output:**

- Equations of state of matter in Core Collapse supernova (CCSN) and neutron star,
- Impact of strangeness on CCSN simulations and evolution of protoneutron stars,
- Superfluidity in neutron star matter,
- Frame dragging effect in rotating neutron stars and its observable consequences,
- Magneto-elastic oscillations of neutron stars and its connection to observed quasi-periodic oscillations in giant flares of magnetars,
- Survey for pulsars with the upgraded GMRT, a pathfinder for the Square Kilometre Array (SKA).

8. Future research/development plan:

- Investigation of tidal deformability in the late inspiralling phase of NS-NS binaries and understanding the universal relations among moment of inertia, Love numbers and Quadrupole moment,
- Study of hypermassive neutron stars (HMNSs) formed in neutron star mergers with exotic equations of state and its imprint on gravitational waves in connection with the LIGO-India project,
- A model for superfluid neutron stars with entrainment effect and its application to pulsar glitches.
- Collaboration with the Indian Neutron Star Physics Community and participation in the science programme of the SKA.

9. List of selected publications:

1. Gravitomagnetic effect in magnetized neutron stars, D. Chatterjee, C. Chakraborty, D. Bandyopadhyay, **JCAP 01** (2017) 062

2. Neutron star physics in the SKA era: An Indian perspective, S. Konar, M. Bagchi, D. Bandyopadhyay et al., **Journal of Astrophysics and Astronomy** (2016) 37:36

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5. Slowly rotating superfluid neutron stars with isospin dependent entrainment in a two-fluid model, A. Kheto and D. Bandyopadhyay, **Phys. Rev. D91** (2015) 043006

6. New hyperon equations of state for supernovae and neutron stars in density dependent hadron field theory, S. Banik, M. Hempel and D. Bandyopadhyay, **Astrophysical Journal Supplement Series** 214 (2014) 22

7. Dragging of inertial frames inside the rotating neutron stars, C. Chakraborty, K.P. Modak and D. Bandyopadhyay, **Astrophysical Journal 790** (2014) 2

8. Inner Crusts of Neutron Stars in Strongly Quantizing Magnetic Fields, R. Nandi, D. Bandyopadhyay, I. N. Mishustin and W. Greiner, **Astrophysical Journal 736** (2011) 156.

9. Hyperon bulk viscosity in strong magnetic fields, M. Sinha and D. Bandyopadhyay;**Phys. Rev. D79** (2009) 123001.

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11. Effect of hyperon-hyperon interaction on bulk viscosity and r-mode instability in neutron stars, D. Chatterjee and D. Bandyopadhyay, **Phys. Rev. D74** (2006) 023003.

12. Color superconducting quark matter core in the third family of compact stars, S. Banik and D. Bandyopadhyay, **Phys. Rev. D67** (2003) 123003.

13. Third family of superdense stars in the presence of antikaon condensates, S. Banik and D. Bandyopadhyay, **Phys. Rev. C64** (2001) 055805.

14. Rapid cooling of magnetized neutron stars, D. Bandyopadhyay, S. Chakrabarty, P. Dey and S. Pal, **Phys. Rev. D58** (1998) 121301(R).

15. Quantizing magnetic field and quark-hadron phase transition in a neutron star, D. Bandyopadhyay, S. Chakrabarty and S. Pal, **Physical Review Letters 79** (1997) 2176.

16. Dense Nuclear Matter in a Strong Magnetic field, S. Chakrabarty, D. Bandyopadhyay and S. Pal, **Physical Review Letters 78** (1997) 2898.

ACADEMIC PROFILE (July 2017)

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Educational Background :
• Ph.D. (Theoretical Physics) : Imperial College, University of London, London, England.
Thesis : *Implications of phase transitions in the early universe* (1984) (Advisor : (Late) Prof. T.W.B. Kibble, CBE, FRS).
• Ph.D. (Physics) : Delhi University, Delhi, India.
Thesis : *Application of Quantum Chromodynamics to quark matter* (1981) (Advisor : (Late) Prof. S.N. Biswas).
• M.Sc. (Physics) : Delhi University, Delhi, India : 1st Class (1976).
• B.Sc. (Physics) : Gauhati University, Guwahati, Assam, India : 1st Class (1974).

Special Fellowships, Awards, etc. :
• January — December 2013: The Clark way Harrison Distinguished Visiting Professorship at the McDonnell Center for the Space Sciences & Physics Department, Washington University, St. Louis, MO, USA.
• January 1997 – January 1999: U. S. National Academy of Sciences (NAS)/National Research Council (NRC) Resident Senior Research Associateship at the Laboratory for High Energy Astrophysics of NASA/Goddard Space Flight Center, Greenbelt, Maryland, USA.
• October 1980–January 1984 : "1851 Exhibition Fellowship" of the "1851 Royal Commission", London, England. Worked at the Theoretical Physics Group, The Blackett Laboratory, Imperial College, London, England.

Faculty Positions :
• November 2005 – present : Saha Institute of Nuclear Physics (SINP), Kolkata, India :
– Professor and Sr. Prof. (from Aug. 2009) of the Theory Division, SINP, and subsequently, Sr. Prof. & Head (from June 2010 till Oct. 2014) of the AstroParticle Physics & Cosmology (APC) Division (created in June 2010).
• November 1992– October 2005 : Indian Institute of Astrophysics, Bangalore, India :
– Fellow (till Sept. 1996), Reader (till Sept. 1998), Reader-II (till Sept. 2001), and Assoc. Prof. (till Oct. 2005).

Post-doctoral Positions :
• March 1989 – February 1992 : Astronomy & Astrophysics Center, Enrico Fermi Institute, University of Chicago, Chicago, USA, & NASA/Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, Batavia, Illinois, USA
• May 1985 – February 1989 : Tata Institute of Fundamental Research, Bombay, India

Current areas of research :
• Topics, in general, on the interface areas between High Energy Particle Physics and Astrophysics/Cosmology.
• Nature and distribution of Dark Matter in the Galaxy.
• Physics and Astrophysics of Ultrahigh-energy (UHE) cosmic rays (CR), gamma rays and neutrinos
• Experimental Search for WIMP Dark Matter particles

Selected Publications :
• *Dark Matter Search Results from the PICO-60 C_3F_8 Bubble Chamber*,
C. Amole et al. (PICO Collaboration), Phys. Rev. Lett. **118**, 251301 (2017) [arXiv:1702.07666].
• *Detecting supernova neutrinos with iron and lead detectors*,
Abhijit Bandyopadhyay, Pijushpani Bhattacharjee, Sovan Chakraborty, Kamales Kar, Satyajit Saha, Phys. Rev. D **95**, 065022 (2017) [arXiv:1607.05591].

• *Constraints on the synchrotron self-Compton mechanism of TeV gamma ray emission from the Milagro TeV source MGRO J2019+37 within the pulsar wind nebula scenario*,
Lab Saha, Pijushpani Bhattacharjee, Jour. High Energy Astrophys. (JHEAP) **5–6**, 9–14 (2015) [arXiv:1402.4309].

• *Rotation Curve of the Milky Way out to $\sim$ 200 kpc*,
Pijushpani Bhattacharjee, Soumini Chaudhury, and Susmita Kundu, Astrophys. J. **785**, 63 (2014).

• *Observing supernova neutrino light curve in future dark matter detectors*,
Sovan Chakraborty, Pijushpani Bhattacharjee and Kamales Kar, Phys. Rev. **D89**, 013011 (2014).

• *Deriving the velocity distribution of Galactic dark matter particles from the rotation curve data*,
Pijushpani Bhattacharjee, Soumini Chaudhury, Susmita Kundu, and Subhabrata Majumdar, Phys. Rev. **D 87**, 083525 (2013).

• *Neutrinos from WIMP annihilations in the Sun: Implications of a self-consistent model of the Milky Way's dark matter halo*,
Susmita Kundu and Pijushpani Bhattacharjee, Phys. Rev. **D 85**, 123533 (2012).

• *Direct detection of WIMPs : Implications of a self-consistent truncated isothermal model of the Milky Way's dark matter halo*,
Soumini Chaudhury, Pijushpani Bhattacharjee and Ramanath Cowsik, JCAP **09** (2010) 020.

• *Upper Limit on the Cosmic Gamma-Ray Burst Rate from High Energy Diffuse Neutrino Background*,
P. Bhattacharjee, S. Chakraborty, S. Das Gupta, and K. Kar, Phys. Rev. **D77**, 043008 (2008).

• *Probing neutrino mixing angles with ultrahigh energy neutrino telescopes*,
P. Bhattacharjee and N. Gupta, arXiv:hep-ph/0501191.

• *$B - L$ cosmic strings and baryogenesis*,
P. Bhattacharjee, N. Sahu and U. A. Yajnik, Phys. Rev. **D70**, 083534 (2004).

• *The proton synchrotron model of TeV gamma ray bursts and their detectability by AMANDA/ICECUBE type detectors*,
P. Bhattacharjee and N. Gupta, Astroparticle Phys. **20**, 169 (2003).

• *Origin and Propagation of Extremely High Energy Cosmic Rays*,
P. Bhattacharjee and G. Sigl, Physics Reports **327**, 109–247 (2000).

• *Cosmic Topological Defects, Highest Energy Cosmic Rays, and the Baryon Asymmetry of the Universe*,
P. Bhattacharjee, Phys. Rev. Lett. **81**, 260 (1998).

• *Tev and Superheavy Particles from Supersymmetric Topological Defects, the Extragalactic Gamma Ray Background, and the Highest Energy Cosmic Rays*,
P. Bhattacharjee, Q. Shafi, and F.W. Stecker, Phys. Rev. Lett. **80**, 3698–3701 (1998).

• *Dispersion velocity of Galactic dark matter particles*,
R. Cowsik, C. Ratnam and P. Bhattacharjee, Phys. Rev. Lett. **76**, 3886 (1996).

• *Survivability of cosmological quark nuggets in the chromoelectric flux-tube fission model of baryon evaporation*,
P. Bhattacharjee, J. Alam, B. Sinha, and S. Raha, Phys. Rev. **D48**, 4630 (1993); **D49**, 4306 (1994) (Erratum).

• *Grand unified theories, topological defects and ultrahigh-energy cosmic rays*,
P. Bhattacharjee, C.T. Hill, and D.N. Schramm, Phys. Rev. Lett. **69**, 567 (1992).

• *Cosmic strings and ultrahigh-energy cosmic rays*,
P. Bhattacharjee, Phys. Rev. **D40**, 3968–3975 (1989).

• *Baryon number from collapsing cosmic strings*,
P. Bhattacharjee, T.W.B. Kibble, and N. Turok, Phys. Lett. **B 119**, 95 (1982).

• *Possible existence of quark-stars*,
J. D. Anand, P. Bhattacharjee, and S. N. Biswas, Jour. Phys. **A12**, L347 (1979).

Name	Debasish Majumdar
Date of Birth	October 20, 1963
Designation	Professor G
Division	Astroparticle Physics and Cosmology
	Saha Institute of Nuclear Physics. Kolkata
Ph.D.	1995
	Physical Research Laboratory, Ahmedabad
	Thesis submitted - December, 1994
	Degree Awarded - The M.S. University of Baroda, Vadodara, 1995

Previous Appointments

Year	Position	Institution
1988-1994	Research Scholar	Physical Reasearch Laboratory Ahmedabad
1994-1995	Post Doctoral Fellow	Physical Research Laboratory
1995-1997	Post Doctoral Fellow	Institute of Physics Bhubaneswar
1997-2000	Research Associate	Department of Physics University of Calcutta
2000-2003	Research Associate	Saha Institute of Nuclear Physics Kolkata
2003-2005	Visiting Scientist	Saha Institute of Nuclear Physics
2005-present	Faculty	Saha Institute of Nuclear Physics

Expertise

My research spread over three fields namely *Particle Dark Matter physics* and *Dark Energy*, *Neutrino physics* and Nuclear astrophysics.

My present interest is extensively on *Dark Matter physics*. In order to explain various possible indirect signatures of Dark Matter as well as the recently observed self interaction of Dark Matter in Abell cluster by one single framework of particle Dark Matter model, I along with my students and collaborators proposed a new two component Dark Matter model in one single framework, where the mass of the two components are separated by orders of magnitude (keV and GeV).

I have done extensive work on *Neutrino Oscillation phenomenology.* I have also expertise in the ICAL (Iron calorimeter) simulation work for the proposed *INO (India-based neutrino observatory).* I dveloped intelligent technique to calculate the curvature of a given muon track in the detector I also developed at the initial stage, a methodology to identify a track from the background.

I along with his sudent gave general form for various types Thawing Dark Energy Models.

I have developed a theory for calculating the *beta decay strength densities* and used them to obtain a formalism to compute beta decay rates at finite temperature relevant for supernova stars.

Research Interests Dark Matter, Neutrino Physics, Dark Energy

Some selected publications

1. Anirban Biswas, *Debasish Majumdar*, Probir Roy, "Nonthermal two component dark matter model for Fermi-LAT γ-ray excess and 3.55 keV X-ray line". JHEP **1504**, 065 (2015).

2. Kamakshya Prasad Modak, *Debasish Majumdar*, (2015), "Confronting Galactic and Extragalactic γ-rays Observed by Fermi-Lat With Annihilating Dark Matter in an Inert Higgs Doublet Model" Astrophys. J. Suppl. **219**, 37 (2015).

3. Kamakshya Prasad Modak, *Debasish Majumdar*, Subhendu Rakshit, "A Possible Explanation of Low Energy γ-ray Excess from Galactic Centre and Fermi Bubble by a Dark Matter Model with Two Real Scalars", JCAP **1503** 011, (2015), 42 pages.

4. Debabrata Adak, *Debasish Majumdar*, Supratik Pal, “Generalizing thawing dark energy models: the standard vis-à-vis model independent diagnostics”. Mon. Not. Roy. Astron. Soc. **437**, 831-842 (2014).

5. Anirban Biswas, *Debasish Majumdar*, Arunansu Sil, Pijushpani Bhattacharjee, (2013), “Two Component Dark Matter : A Possible Explanation of 130 GeV γ Ray Line from the Galactic Centre”. JCAP **1312**, 049 (2013).

6. Abhijit Bandyopadhyay, *Debasish Majumdar*, “On Diurnal and Annual Variations of Directional Detection Rates of Dark Matter”. Astrophys. J. **746**, 107 (2012).

7. Abhijit Bandyopadhyay, Sovan Chakraborty, Ambar Ghosal, *Debasish Majumdar*, (2010), “Constraining Scalar Singlet Dark Matter with CDMS, XENON and DAMA and Prediction for Direct Detection Rates”. JHEP **1011**, 065 (16 pages).

8. *Debasish Majumdar* and Ambar Ghosal, “Probing deviations from tri-bimaximal mixing through ultra high energy neutrino signals”. Phys. Rev. D **75**, 113004 (2007).

9. *Debasish Majumdar*, “Relic densities for Kaluza-Klein dark matter”, Mod. Phys. Lett. A **18**, 1705-1710 (2003).

10. *Debasish Majumdar*, “Detection rates for Kaluza-Klein dark matter”, Phys. Rev. D **67**, 095010 (2003).

11. Ambar Ghosal and *Debasish Majumdar*, “Texture of neutrino mass matrix in view of recent neutrino experimental results”, Phys. Rev. D **66**, 053004 (2002).

12. *Debasish Majumdar*, “Mass and scalar cross-sections for neutralino dark matter in anomaly mediated supersymmetry breaking model”. J. Phys. G **28**, 2747-2753 (2002).

13. *Debasish Majumdar*, Amitava Raychaudhuri and Arunansu Sil, “Solar neutrino results and violation of the equivalence principle: An Analysis of the existing data and predictions for SNO”. Phys. Rev. D **63**, 073014 (2001).

14. Srubabati Goswami, *Debasish Majumdar* and Amitava Raychaudhuri, “Solar neutrino rates, spectrum, and its moments: An MSW analysis in the light of Super-Kamiokande results”. Phys. Rev. D **63**, 013003 (2001).

15. Sandhya Choube, Srubabati Goswami and *Debasish Majumdar*, “Status of the neutrino decay solution to the solar neutrino problem”. Phys. Lett. B **484**, 73-78 (2000).

16. *Debasish Majumdar*, Kamales Kar, Alak Ray, Amitava Raychaudhuri and Firoza K. Sutaria, “Oscillation effects on neutrinos from the early phase of a nearby supernova”. Int. J. Mod. Phys. A **15**, 2105-2120 (2000).

17. *Debasish Majumdar* and Amitava Raychaudhuri, “New variables for neutrino oscillation diagnostics at Super-Kamiokande and the Sudbury Neutrino Observatory”. Phys. Rev. D **60**, 053001 (1999).

18. V.K.B. Kota and *D. Majumdar*, (1995) “Bivariate distributions in statistical spectroscopy studies: IV. Interacting particle Gamow-Teller strength densities and -decay rates of fp-shell nuclei for presupernova stars”, Z. Phys. A **351**, 377-383 (1995).

Books/Monographs

1. Debasish Majumdar, (2014), **Dark Matter: An Introduction**, CRC Press, Taylor and Francis, 263 pages.

1. **NAME** : **AMBAR GHOSAL**

(Astroparticle Physics and Cosmology Division)

2. **Educational Qualification** Ph.D in "High Energy Physics, Theory",Visva-Bharati, Santiniketan, India, August 1997.

Academic recognitions

(a) National Merit Scholarship, 1980. (b) JSPS (Japan Society for the Promotion of Science) Post Doctoral Fellowship for Foreign Researchers, February, 2000.

3.**Academic Profile**

(a) At Harish Chandra Research Institute of Mathematics and Mathematical Physics, Chhatnag Road, Jhusi, Allahabad 211 019, India as Visiting Fellow from September 1996 to September 1998. b) At Saha Institute of Nuclear Physics , T.N.P. Division, Sector- 1, Block- AF, Bidhannagar, Kolkata 700 064, India as Research Associate from September 1998 to January 2000. c) At University of Shizuoka, Department of Physics, 52-1 Yada, Shizuoka-shi, Shizuoka, Japan 422 8526 as a JSPS Post Doctoral Fellow from February 2000 to January 31, 2002. d) At Saha Institute of Nuclear Physics , Sector- 1, Block- AF, Bidhannagar, Kolkata 700 064, India as Visiting Scientist from March 07, 2002 to April 04, 2005. e) At Saha Institute of Nuclear Physics , Sector- 1, Block- AF, Bidhannagar, Kolkata 700 064, India as Associate Professor 'E' from April 07, 2005, as Professor 'F' from August 01,2007, as Professor 'G' from January 2013 (till continuing).

3. Research Students: i) Dr. Mainak Chakraborty: Ph.D degree awarded in the year 2016, presently he is a Post Doctoral Fellow at 'Siksha O Anusandhan University', Bhubaneswar, India. ii) Mr. Rome Samanta : Joined on August 2014, till continuing. iii) Mr. Roopam Sinha : Joined on August 2014, till continuing.

4. Research Plan: We have planned to investigate models of neutrino mass advocating two basic ideas i) Residual symmetry approach along with some flavor invariance ii) Generation of neutrino mass due to diffrent mechanisms. We have recently investigated a model of neutrino mass with complex scaling property within the elements of M_ν. We have also studied Baryogenesis via Leptogenesis extensively by solving network of Boltzmann equations. Further extension of the above ansatz within the framework of Type I seesaw mechanism has also carried out. In pursuance we have planned to investigate with other symmetry property of the neutrino mass matrix through different mechanisms to generate neutrino mass as well as mixing and the phenomena of Baryogenesis through Leptogenesis.

5. List of publications
(April 2012- December 2016)

1. R. Samanta, P. Roy and **A. Ghosal**, "Extended scaling and residual flavor symmetry in the neutrino Majorana mass matrix," Eur. Phys. J. C **76**, 662 (2016).
2. R. Samanta, P. Roy and **A. Ghosal**, "Complex Scaling in Neutrino Mass Matrix," Acta Phys. Polon. Supp. **9**, 807 (2016).
3. R. Sinha, R. Samanta and **A. Ghosal**, "Maximal Zero Textures in Linear and Inverse Seesaw," Phys. Lett. B **759**, 206 (2016).
4. R. Samanta and **A. Ghosal**, "Probing maximal zero textures with broken cyclic symmetry in inverse seesaw," Nucl. Phys. B **911**, 846 (2016).
5. R. Samanta, M. Chakraborty and **A. Ghosal**, "Evaluation of the Majorana Phases of a General Majorana Neutrino Mass Matrix: Testability of hierarchical Flavour Models," Nucl. Phys. B **904**, 86 (2016).
6. B. Adhikary, M. Chakraborty and **A. Ghosal**, "Flavored leptogenesis with quasidegenerate neutrinos in a broken cyclic symmetric model," Phys. Rev. D **93**, 113001 (2016).
7. **A. Ghosal** and R. Samanta, "Probing texture zeros with scaling ansatz in inverse seesaw," JHEP **1505**, 077 (2015).
8. M. Chakraborty, H. Z. Devi and **A. Ghosal**, "Scaling ansatz with texture zeros in linear seesaw," Phys. Lett. B **741**, 210 (2015).
9. B. Adhikary, **A. Ghosal** and P. Roy, "Maximal zero textures of the inverse seesaw with broken $\mu\tau$ symmetry," Indian J. Phys. **88**, 979 (2014).
10. B. Adhikary, M. Chakraborty and **A. Ghosal**, "Masses, mixing angles and phases of general Majorana neutrino mass matrix," JHEP **1310**, 043 (2013), Erratum: [JHEP **1409**, 180 (2014)].
11. B. Adhikary, **A. Ghosal** and P. Roy, "θ_{13}, $\mu\tau$ symmetry breaking and neutrino Yukawa textures," Int. J. Mod. Phys. A **28**, 1350118 (2013).
12. B. Adhikary, M. Chakraborty and **A. Ghosal**, "Scaling ansatz, four zero Yukawa textures and large θ_{13}," Phys. Rev. D **86**, 013015 (2012).

Name : Mala Das
Designation : Associate Professor F
Division : Astroparticle Physics & Cosmology

Educational Background :

Ph.D (Experimental Physics) : (2001), Bose Institute ; University of Calcutta
MSc (Physics) : (1995), University of Calcutta
BSc : (1993), Vidhyasagar College for Women ; University of Calcutta (*Abani Banerjee medal*)

Career Profile :

1. 2001 – 2002 : 2004 - 2005 : VECC, Kolkata (post-doctoral fellow)
2. 2002 - 2004 : Hokkaido University, Japan (*JSPS fellowship*)
3. 2007 : Low noise underground lab (LSBB), France, SIMPLE collaboration
4. 2005 – 2010 : SINP (RA & DST WOS-A) & Univ. de Montreal, Canada (visiting) under PICASSO collaboration.
5. 2010, July - 2016, June : Associate Prof E at Saha Institute of Nuclear Physics.
6. 2016, July – present : Associate Prof. F at Saha Institute of Nuclear Physics.

Research Interest :

- Laboratory set-up at SINP for dark matter search experiment using superheated liquid detector.

- Participation to the PICASSO (Project In Canada to Search for Supersymmetric Objects), presently PICO (PICASSO+COUPP) dark matter search experiment at SNOLab, Canada, involved in data analysis, detector simulation, PICASSO detector fabrication{nickname : Meghla Akash}, large mass detector R & D. Recently, the mechanical design of the camera holding system for viewing the bubble nucleation for upcoming PICO-40/500 chamber has been completed at SINP.

- Experimental studies and simulation on the gamma ray, neutron and alpha particle induced bubble nucleation in superheated droplets at SINP-lab.

- Simulation and measurement for the Dark matter direct search experiment for mini-DINO (Dark Matter at India-based Neutrino Observatory) at UCIL mine, Jaduguda to be installed finally at INO, India as DINO.

- Efforts is going on to measure the neutron dose & spectrum with self-made superheated liquid detector in and around the patient when the patient body is irradiated with high energy x-ray beam in medical accelerator in India.

Publications (2012 – present) :

1. M Das in PICO collaboration (2017), "Dark Matter Search Results from the PICO-60 C3F8 Bubble Chamber", ***Phys. Rev. Lett.*** **118**, 251301 [& PRL Editor's suggestion].

2. M Das in PICASSO collaboration (2017), "Final result of the PICASSO dark matter search experiment", ***Astroparticle Phys.*** **90**, 85.

3. Mala Das, Nilanjan Biswas (2017), "Detection of bubble nucleation event in superheated drop detector by pressure sensor", ***Pramana J of Phys***.88, 97-101.

4. Susnata Seth, Mala Das (2016), "Radiation LET and drop size dependence of the low frequency signal from tiny superheated droplets", ***Nucl. Instrum. Meth A*** **837**, 92.

5. M. Das in PICO collaboration (2016), "Improved dark matter search result from PICO-2L run-2", ***Phys. Rev. D (rapid)*** **93**, 061101.

6. Susnata Seth, Mala Das (2016), "The simulation of the response of superheated emulsion to alpha particles", ***Journal of Instrumentation*** **11**, 04015.

7. M. Das in PICO collaboration (2016), "Dark Matter search results from the PICO-60 CF3I bubble chamber" ***Phys. Rev. D*** 93,052014.

8. M. Das in PICO collaboration (2015), "Dark Matter search results from the PICO-2L C3F8 bubble chamber", ***Phys. Rev. Lett.*****114**, 231302.

9. Prasanna K Mondal, Susnata Seth, Mala Das, Pijushpani Bhattacharjee (2013), "Study of low frequency acoustic signals from superheated droplet detector", ***Nucl. Instrum. Meth.*** **A729**, 182-187.

10. S Seth, M Das, S Bhattacharya, P Bhattacharjee, S Saha (2013), "The nucleation parameter for heavy ion induced bubble nucleation in superheated emulsion detector", ***Journal of Instrumentation*** **8**, Issue 5, P05001.

11. Mala Das & Susnata Seth (2013), "Searching for universal behaviour in superheated droplet detector with effective recoil nuclei", ***Pramana J of Physics*** **80**, Issue 6, 989-994.

12. M Das in PICASSO collaboration (2012), "Constraints on low-mass WIMP interaction on ^{19}F from PICASSO", ***Phys. Lett.B*** **711**, May, 153-161.

Curriculum Vitae

Name : Pratik Majumdar
Date of birth : 9th July, 1973
Present position : Associate Professor 'E'
Division : Astroparticle Physics and Cosmology (APC)
Earlier employment data :
Research Scholar, TIFR - Mumbai, India (January 1997 – August 2003)
Visiting Research Scholar, INFN - Pisa, Italy (September 2003 – May 2004)
Post-doctoral Fellow, Max Planck Institut für Physik Munich (July 2004 – March 2008)
Post-doctoral Research Fellow, DESY, Zeuthen (April 2008 – November 2009)
Staff Research Associate, Department of Physics and Astronomy, University of California, Los Angeles (December 2009 – January 2012)
Associate Professor 'E', Saha Institute of Nuclear Physics, (February 2012 - till date)

Research Activities Currently involved in :

- Observational TeV gamma-ray astrophysics using the Major Atmospheric Gamma Imaging Cerenkov (MAGIC) [1] telescopes. Full member of the MAGIC collaboration.
- Probing the origin of cosmic rays via analysis of GeV-TeV data from Fermi-LAT and MAGIC telescopes through observations of supernova remnants, pulsar wind nebulae and active galactic nuclei.
- Member of the Software Board of the MAGIC telescope collaboration.
- Working group Leader of the Galactic Physics group of MAGIC telescope collaboration.
- Absolute Light Calibration of MAGIC telescopes using muons. Monte-Carlo-data comparisons
- Design and development of a calibration system for the calibration of the camera of the Large Size Telescope for future generation of an array of imaging Cerenkov telescopes (Cerenkov Telescope Array)
- Analysis of data from dwarf spheroidal galaxies using Fermi-LAT detector for indirect detection of dark matter.

Accomplishments :

- Design and development of a calibration system for the calibration of the camera of the Large Size Telescope for future generation of an array of imaging Cerenkov telescopes (Cerenkov Telescope Array). This calibration system has been developed indigenously and has been fully characterised in the laboratory. It will be installed at the observatory site at La Palma, Canary Islands, Spain in 2017 where the MAGIC telescopes are operating.
- Study of origin of galactic cosmic rays by analysing data from Fermi-LAT detector and MAGIC telescope system and understanding the origin of TeV gamma rays in active galactic nuclei leading to generation of very high quality publications in reputed high impact factor journals.

Future Research Plans :

- Develop the concept of Silicon Photomulitipliers as novel detectors for TeV gamma-ray astrophysics experiments. There are several advantages over standard photomultipliers currently being used, but there are several disadvantages also. A thorough study for silicon photomultiplier detector development is required. Eventually we plan to build a camera with silicon photomultipliers for the future generation of telescopes of Cerenkov Telescope Array (CTA).
- Development of calibration systems for the Large Size Telescopes (LST) of CTA.
- Continue the study of origin of galactic cosmic rays by analysing data from Fermi-LAT detector and MAGIC telescope system and understanding the origin of TeV gamma rays in active galactic nuclei and extra-galactic background light (EBL) which gives valuable clues to various cosmological parameters eventually leading to generation of very high quality publications in reputed high impact factor journals.

[1] http://wwwmagic.mppmu.mpg.de

- Multimessenger Astrophysics with synergies between very high energy gamma rays (MAGIC/CTA), X-rays (ASTROSAT and other X-ray detectors), radio waves (GMRT,SKA), optical (HCT,TMT), neutrinos (IceCube) and gravitational waves (LIGO).

Selected Important Publications (including Internal Notes and Technical Reports) :

- **Very-High-Energy gamma rays from a Distant Quasar: How Transparent Is the Universe?**, J.Albert et al, Science, Volume 320, Issue 5884, pp. 1752- (2008), [2] Total Citations : 294
- **VHE $\gamma-$ Ray Observation of the Crab Nebula and its Pulsar with the MAGIC Telescope**, J.Albert et al, Astrophysical Journal, Volume 674, Issue 2, article id. 1037-1055, pp. (2008), Total Citations : 261
- **Monte Carlo simulation for the MAGIC telescope**, **P.Majumdar** et al, Proceedings of the 29th International Cosmic Ray Conference. August 3-10, 2005, Pune, India, Total Citations : 20
- **Angular resolution of the Pachmarhi array of Cerenkov telescopes**, **P. Majumdar** et al, Astroparticle Physics, Volume 18, Issue 4, p. 333-349 (2003), Total Citations :12
- **Observations of the Unidentified Gamma-Ray Source TeV J2032+4130 by VERITAS**, E.Aliu et al, Astrophysical Journal, 783, 16 (2014), Total Citations : 24
- **Origin of gamma-ray emission in the shell of Cassiopeia A**, L. Saha, T. Ergin, **P. Majumdar**, M. Bozkurt and E. N. Ercan, Astronomy and Astrophysics, Volume 563, A88, (2014), Total Citations : 6
- **Recombining Plasma in the Gamma-Ray-emitting Mixed-morphology Supernova Remnant 3C 391**, Ergin, T.; Sezer, A.; Saha, L.; **Majumdar, P.**; Chatterjee, A.; Bayirli, A.; Ercan, E. N. , Astrophysical Journal, Volume 790, Issue 1, article id. 65, 10 pp. (2014), Total Citations : 8
- **Searching for Overionized Plasma in the Gamma-ray-emitting Supernova Remnant G349.7+0.2**, Ergin, T.; Sezer, A.; Saha, L.; **Majumdar, P.**; Gök, F.; Ercan, E. N., Astrophysical Journal, Volume 804, Issue 2, article id. 124, 10 pp. (2015), Total Citations : 2
- **Long term study of the light curve of PKS 1510-089 in GeV energies**, R.Prince, **P. Majumdar** and N.Gupta, accepted to be published in Astrophysical Journal on 6th June 2017, arXiv/1706.02133
- **Using Muon Rings for the Optical Throughput Calibration of the Cerenkov Telescope Array**, M.Gaug, T.Armstrong, K.Bernlohr, M.Daniel, M.Errando, M.C.Maccarone, **P.Majumdar**, T.Mineo, A.Mitchell, R.Moderski, D.Parsons, E.Prandini and S.Toscano, Internal Note for the Common Calibration Working group of CTA Consortium, CTA Report COM-CCF/150310 (2015)
- **Design of a prototype device to calibrate the Large Size Telescope camera of the Cherenkov Telescope Array**, Iori, M.; **Majumdar, P.**; De Persio, F.; Chatterjee, A.; Ferrarotto, F.; Nagesh, B. K.; Saha, L.; Singh, B. B., Proceedings of the 34th International Cosmic Ray Conference (ICRC2015)
- **Creating a high-resolution picture of Cygnus with the Cherenkov Telescope Array**, Weinstein, Amanda; Aliu, Ester; Casanova, Sabrina; Di Girolamo, Tristano; Dyrda, Michael; Hahn, Joachim; **Majumdar, Pratik**; Rodriguez, Jerome; Tibaldo, Luigi; for the CTA Consortium, Proceedings of the 34th International Cosmic Ray Conference (ICRC2015)
- **The Camera Calibration Strategy of the Cherenkov Telescope Array**, M. K. Daniel, M. Gaug and **P. Majumdar**; for the CTA Consortium, Proceedings of the 34th International Cosmic Ray Conference (ICRC2015)

[2] first discovery of a quasar at high redshift in very high energy gamma rays

National Level Academic Review

Theory Division

A Report for the period 2012-2017

Present Staff

Faculty Members (13)	Technical (2)
Amit Ghosh, Professor G	Prodyut Kumar Mitra
Arnab Kundu, Associate Professor E	Sangita Pande
Asit Kumar De, Senior Professor H & Head	
Bijay Kumar Agrawal, Senior Professor H	
Bireswar Basu-Mallick, Senior Professor H	
Gautam Bhattacharyya, Senior Professor H+	
Harvendra Singh, Professor G	
Koushik Dutta, Associate Professor E	
Kumar Sankar Gupta, Senior Professor H+	**Administrative/Auxiliary (2)**
Munshi Golam Mustafa, Senior Professor H+	Dola Mallick
Palash Baran Pal, Senior Professor H+	Arun Kumar Bose
Prakash Mathews, Professor G	
Shibaji Roy, Senior Professor H+	

Adjunct Professor of Theory Division: Ashok Das, University of Rochester, USA

Present Postdoctoral Fellows & Inspire Faculty Members

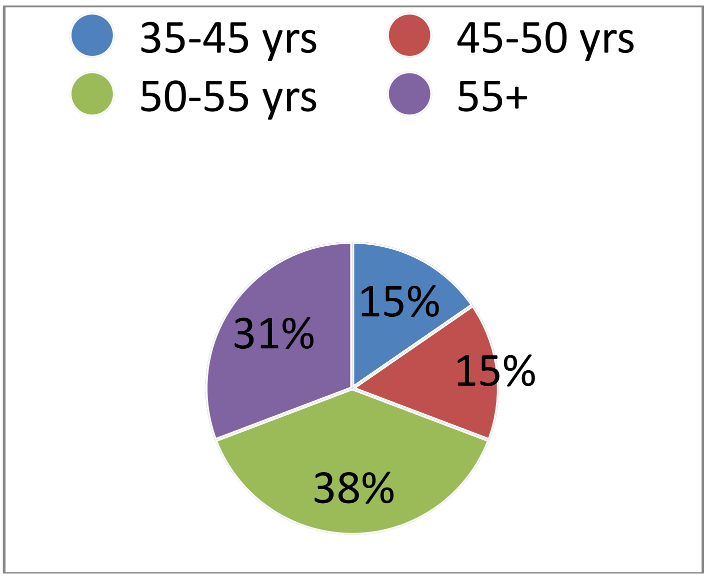
Serial No.	Name	Year of Joining
1	Rudranil Basu (PhD, SNBNCBS, 2013), DST Inspire Faculty	2015
2	Nilanjana Kumar (PhD, Northern Illinois Univ, 2016), Post-doc	2017
3	Mayukh Raj Gangopadhyay (PhD, Notre Dame Univ, 2017), Post -doc	2017
4	Maguni Mahakhud (PhD, HRI, 2016), Post-doc	2017
5	Dharmesh Jain (PhD, Stony Brook Univ, 2013), Post-doc	2017

Scientists superannuated from SINP/elsewhere holding DST projects currently hosted by the Theory Division

Serial No.	Name	Project	Valid till
1	Jadu Nath De	SERB, DST	2020
2	Radhey Shyam	SERB, DST	2018

Members superannuated / deceased in service (since 2012)

Faculty Members (8)	Technical (1)
Anjan Kundu, Senior Professor H+ (deceased in service on 31 Dec. 2016)	Sudarsan Hazra (2017)
Avaroth Harindranath, Senior Professor H+ (2016)	
Parthasarathi Mitra, Senior Professor H+ (2016}	
Radhey Shyam, Senior Professor H (2013)	
Debabrata Mukhopadhyay, Professor F (2013)	
Gautam Ghosh, Senior Professor H (2012)	
Tarun Kanti Roy, Professor G (2012)	
Kamales Kar, Senior Professor H+ (2012)	



Age-distribution of the current faculty members of the Theory Division

Present PhD students

Sr. No	Name	Enrollment	Year of joining	Ph.D. Supervisor
1	Aritra Bandyopadhyay	HBNI	2012	Munshi Golam Mustafa
2	Augniva Ray	HBNI	2015	Arnab Kundu
3	Avik Banerjee (junior)	HBNI	2015	Gautam Bhattacharyya
4	Avik Banerjee (senior)	HBNI	2014	Arnab Kundu
5	Chiranjib Mondal	HBNI	2012	Bijay Kumar Agrawal
6	Chitralekha Datta	HBNI	2012	Bireswar Basu-Mallick
7	Kumar Das	HBNI	2012	Koushik Dutta
8	Kuntal Nayek	HBNI	2012	Shibaji Roy
9	Mugdha Sarkar	HBNI	2013	Asit Kumar De
10	Naosad Alam	HBNI	2012	Bijay Kumar Agrawal
11	Rohit Mishra	HBNI	2013	Harvendra Singh
12	Sukannya Bhattacharya	HBNI	2013	Koushik Dutta
13	Udit N. Chowdhury	HBNI	2015	Shibaji Roy, Harvendra Singh

<u>3 new students are expected to join the Theory Division in August 2017</u>

PhD thesis submitted

	Name	Ph.D. Supervisor	Status
1	Chitralekha Datta (HBNI)	Bireswar Basu Mallick	Submitted in July 2017
2	Aritra Bandyopadhyay (HBNI)	Munshi Golam Mustafa	Submitted in July 2017
3	Kumar Das (HBNI)	Koushik Dutta	Submitted in July 2017

PhD thesis to be submitted soon

	Name	Ph.D. Supervisor	Status
2	Chiranjib Mondal (HBNI)	Bijay Agrawal	Thesis work finished. Thesis being written. To be submitted shortly.
3	Naosad Alam (HBNI)	Bijay Agrawal	
4	Kuntal Nayek (HBNI)	Shibaji Roy	

Ph.D. Degree awarded/provisional certificate awaited (Since 2013)

Sr.No	Name	Award	Ph.D. Supervisor	Present Occupation
1	Gautam Das	Thesis defended, awaiting prov. cert. (HBNI)	Prakash Mathews	Joining as post-doc DESY, Hamburg, Germany
2	Chowdhury Aminul Islam	2017 (HBNI)	Munshi Golam Mustafa	Joining as post-doc, TIFR, Mumbai
3	Avirup Ghosh	2017 (HBNI)	Amit Ghosh	Post-doc, IIT Gandhinagar
4	Arindam Mazumdar	2017 (CU)	Palash Baran Pal	Post-doc, PRL Ahmedabad
5	Atanu Kumar	2016 (HBNI)	Amit Ghosh	Faculty member, Physics, Chandannagar Govt College, WB
6	Baishali Chakraborty	2016 (CU)	Kumar Sankar Gupta	Not available
7	Somdeb Chakraborty	2015 (HBNI)	Shibaji Roy	Faculty member, Maulana Azad College, Kolkata
8	Pratyay Banerjee	2015	Bireswar Basu-Mallick	Faculty member, P.R. Thakur Govt College, WB
9	Dipankar Das	2015 (CU)	Gautam Bhattacharyya	Faculty member, Physics, Univ. of Calcutta (after a post-doc position at Valencia, Spain)
10	Parijat Dey	2015 (CU)	Shibaji Roy	Post-doc, IISc Bangalore
11	Najmul Haque	2015 (HBNI)	Munshi Golam Mustafa	2nd. post-doc, Humboldt fellow, Giessen, Germany (after Kent State Univ, USA)
12	Abhishek Chowdhury	2015 (HBNI)	Avaroth Harindranath	Faculty member, RNLK College, West Medinipur, WB
14	Satyajit Seth	2014 (HBNI)	Prakash Mathews	Post-doc, University of Mainz,Germany; going to Durham, UK for 2nd Post-doc.
15	Kalyan Brata Chatterjee	2014 (CU)	Gautam Bhattacharyya	Faculty, RK Mission VC College, Rahara
16	Pritibhajan Byakti	2014 (CU)	Palash Baran Pal	2nd. Postdoc, IACS Kolkata (after IISc, Bangalore)
17	Raktim Abir	2013 (HBNI)	Munshi Golam Mustafa	Faculty, Aligargh Muslim University (after post-doc at Wayne State Univ, USA)
18	Bhramar Chatterjee	2013 (HBNI)	Amit Ghosh	Not available
19	Santanu Mondal	2013 (HBNI)	Avaroth Harindranath	2nd. Postdoc, NCTU, Taiwan (after Budapest, Hungary)

Important equipment and facility (installed & maintained by the Theory Division)

Advanced Scientific computing facilities:

- CRAY XT5+XE6 (1 cabinet each) of approx. 30 TFlops peak performance
- Medium range parallel cluster with peak performance of 2 TFlops.
- Medium range parallel cluster with peak performance of 7 TFlops
- 300+ TB storage facility
- Software – PBS queue manager, PGI Compilers, Intel Compilers, Cray Compilers, Mathematica, Maple and Matlab

Other Facility:

- Seminar Room with a high quality digital projector (the room is used for lectures of post-MSc coursework, seminars, presentations, meetings and discussions by the whole Institute)

Recent Divisional Academic Activities besides Research

A. TEACHING IN THE POST-MSC CURRICULUM

Class-room teaching : Theory Division faculty members have traditionally taken the major responsibility of teaching in the Pre-PhD (called Post-MSc in SINP) programme of the Institute.

Several members of the Theory Division have either headed the Teaching or convened / co-ordinated these activities. Among the current faculty members, Palash Baran Pal, Asit Kumar De, Amit Ghosh and Munshi Golam Mustafa (current co-ordinator of Post-MSc, Theory curriculum) have successfully spearheaded the teaching programme over the years.

In addition, several members of the Division have given basic (core) and advanced level courses.

Following courses have been offered recently by the Divisional members:

- **Academic Year: 2017 - 18**

  Term I (Aug - Nov)
  - Advanced Quantum Mechanics: Amit Ghosh
  - Quantum Field Theory I: Asit Kumar De

- **Academic Year: 2016 - 17**

  Term I (Aug - Nov)
  - Advanced Quantum Mechanics: Rudranil Basu and Kumar Gupta
  - Quantum Field Theory I: Asit Kumar De

  Term II (Dec - Mar)
  - Quantum Field Theory II - Palash Baran Pal
  - General Relativity and Cosmology - Koushik Dutta

  Term III (Apr - Jul)
  - Topics in String Theory & Field Theory - Arnab Kundu

- **<u>Academic Year: 2015 - 16</u>**

    Term I (Aug - Nov)
    - Advanced Quantum Mechanics - Amit Ghosh
    - Quantum Field Theory I - Asit Kumar De

    Term II (Dec - Mar)
    - Quantum Field Theory II - Asit Kumar De
    - Particle Physics - Palash Baran Pal

    Term III (Apr - Jul)
    - Conformal Field Theory - Arnab Kundu
    - Thermal Field Theory - Munshi Golam Mustafa
    - General Relativity - Amit Ghosh

- **<u>Academic Year: 2014 - 15</u>**

    Term I (Aug -Nov)
    - Mathematical Methods - Palash Baran Pal

    Term II (Dec - Mar)
    - Quantum Field Theory I - Shibaji Roy
    - Inflationary Cosmology - Koushik Dutta

    Term III (Apr - Jul)
    - Quantum Field Theory II - Arnab Kundu
    - General Relativity - Amit Ghosh

- **<u>Academic Year: 2013 - 14</u>**

    Term I (Aug - Nov)
    - Mathematical Methods - Palash Baran Pal
    - Advanced Quantum Mechanics - Asit Kumar De

    Term II (Dec - Mar)
    - Quantum Field Theory I - Harvendra Singh
    - Particle Physics - Prakash Mathews
    - Special Topics in Theoretical Physics - Kumar Gupta

    Term III (Apr - Jul)
    - Quantum Field Theory II - Partha Mitra
    - General Relativity - Amit Ghosh
    - Introduction to Cosmology - Koushik Dutta

- **Academic Year: 2012 - 2013**

  Term I (Aug - Dec)
  - Advanced Quantum Mechanics - Asit Kumar De
  - Field Theory - Parthasarathi Mitra

  Term II (Dec - Apr)
  - Quantum Field Theory - Harvendra Singh
  - Particle Physics - Prakash Mathews
  - Differential & Riemannian Geometry - Amit Ghosh
  - Experimental Techniques - Palash Baran Pal

B. SCIENTIFIC WORKSHOPS / SCHOOLS ORGANISED

Theory Division organises conferences / Workshops / Schools on a regular basis. Following is a list of such recent activities organised by the Theory Division at the SINP Kolkata premises (excluding the ones organised at other venues in collaboration with other organisations):

- (Late) Prof. D.P. Roy Memorial Meeting: 21st April, 2017
- **Saha Theory Workshop**: Aspects of Early Universe Cosmology, January 16-20, 2017.
- **Saha Theory Workshop**: Multi-loop and Multi-leg processes for precision physics at the LHC (Feb 23- 27, 2016)
- Heavy Flavour Meeting (Feb 3-5, 2016)
- **Saha Theory Workshop**: Cosmology at the Interface (28-30 January, 2015)
- Topical Conference on Gravity and Cosmology - Eastern Region (TCGC-ER) - December 13, 2013
- **School** on Quantum Field Theories on Lattice - December 2- 6, 2013
- Advanced **School** on Radiative Corrections for the LHC - April 04-11 , 2011

Currently, preparations are in full swing for the next **Saha Theory Workshop** (19 - 23 Feb 2018) on Aspects of String Theory.

All the past activities (except the DP Roy Meeting) are to be found at the Divisional website page:
http://www.saha.ac.in/web/thd-activities/thd-conferences-workshops

C. VISITOR PROGRAMME & SAHA THEORY SEMINAR SERIES

- The Theory Division hosts a very vibrant visitor programme for scientific discussions. The programme is open to PhD students too. Since April 2012, there have been **81 scientific visitors** to the Theory Division, details of which can be found at the Divisional website page:
  http://www.saha.ac.in/web/thd-visit

- S**aha Theory Seminar Series (STSS)** is one of the very few, if not the only such programme in the country, where seminar speakers (within India) are invited based on a short-list (periodically reviewed) with all expenses covered by the Division. All seminars at the Theory Division (not all of them are STSS) are found at the Divisional website page:
  http://www.saha.ac.in/web/thd-recent-seminar (choose recent & past seminars from the right pane). Since February 2013, there have been **125 seminars** in the Division.

D. RECENT SCIENTIFIC PROJECTS / FUNDING

• Plan Projects for the entire Division

- 12th Plan: Theoretical Physics Across Energy Scales (TPAES)
  Total Approved Financial Outlay: 10.8 Crores
  Start Date: 1 Apr 2012, Completion Date: 30 Sep 2018 (extended)
  Major Components:
    - Installation and Maintenance of Computing Infrastructure
    - Programmes such as
      - Saha Theory Workshop/School
      - Saha Theory Seminar Series
      - Visitor Programme
      - Travel for Collaboration & Attending Conferences etc including Support for Students' Travel

- 11th Plan: Frontiers of Theoretical Physics (FTP)
  Total Approved Financial Outlay: 20.0 Crores
  Physical Target Achieved: Nearly All
  Financial Utilisation: More than 96% of Total Allocation
  Major Outcomes:
    - More than 200 publications in peer-reviewed journals
      - Majority of papers published in journals with IF > 4
    - PhD Degree awarded: 11
    - Installation of High Performance Computing Facilities
      - CRAY XT5 & XE6 systems with massive storage
      - Medium Range Compute Clusters

- **Current Individual Projects / Fellowships**
  - Gautam Bhattacharyya
    - JC Bose National Fellowship, DST, 2017-
    - Principal Investigator (Indian side) of Indo-French Project (No. 5404-2) entitled `Glimpses of New Physics', with S. Vempati (IISc), E. Dudas (Ecole Polytechnique, PI of French side) and Y. Mambrini (Orsay), for the period 1 Feb 2016 to 31 Jan 2019
    - Network coordinator of Multi-Institution Indo-French`Virtual Institute (LIA)' project in Theoretical High Energy Physics with Principal Coordinators: F. Boudjema (LAPTh, Annecy) and R. Godbole (IISc), during 2016-19 [Network: Annecy, Orsay, Grenoble, Lyon, in France; IISc, IMSc, HRI, TIFR, SINP, IISER-Kolkata, IACS, in India]
  - Koushik Dutta
    - Max Planck Society - DST Mobility Grant (2013 - 2017)
    - Ramanujan Fellowship (2013 - 2017)
    - ICTP Associateship
  - Harvendra Singh
    - ICTP Associateship
  - Bireswar Basu Mallick
    - ICTP Associteship

Recent Awards / Honours Received

- Three awards of FNA (Delhi)
- Two awards of FASc (Bangalore)
- One award of FNASc (Allahabad)
- One award of J.C. Bose Fellowship (DST)
- One award of Ramanujan Fellowship (DST)
- One award of Bangabhushan (WB Govt.)

List of Publication (since April 2011)

2011 -12

1. Abhishek Chowdhury, Asit K De, Sangita De Sarkar, A Harindranath, Santanu Mondal, Anwesa Sarkar, Jyotirmoy Maiti, Topological susceptibility in lattice QCD with unimproved Wilson fermions, Physics Letters B707 (2012) 228

2. A Ghosh, P Mitra, Black Hole State Counting in Loop Quantum Gravity, Modern Physics Letters A26 (2011) 1817

3. A Kundu, Integrable twofold hierarchy of perturbed equations and application to optical soliton dynamics, Theoretical and Mathematical Physics 167 (2011) 800

4. Amit Ghosh, Alejandro Perez, Black Hole Entropy and Isolated Horizons Thermodynamics, Physical Review Letters 107 (2011) Art No: 241301

5. Anjan Kundu, Hidden possibilities in controlling optical soliton in fiber guided doped resonant medium, AIP Advances 1 (2011) Art No: 022137

6. Asmaa Abada, Gautam Bhattacharyya, Debottam Das, Cric Weiland, A possible connection between neutrino mass generation and the lightness of a NMSSM pseudoscalar, Physics Letters B700 (2011) 351

7. Ashok Das, H Falomir, M Nieto, et al, Aharonov-Bohm effect in a class of noncommutative theories, Physical Review D84 (2011) Art No: 045002

8. Ashok Das, J Frenkel, The thermal chiral anomaly in the Schwinger model, Physics Letters B704 (2011) 85

9. Ashok Das, Jnanadeva Maharana, Phenomenological implications of S-duality symmetry, Physics Letters B699 (2011) 264

10. Ashok Das, J Gamboa, F Medez, F Torres, Generalization of the Cooper pairing mechanism for spin-triplet in superconductors, Physics Letters A375 (2011) 1756

11. Asit K De, A Harindranath, Santanu Mondal, Effect of r averaging on chiral anomaly in lattice QCD with Wilson fermion: finite volume and cutoff effects, Journal of High Energy Physics, Issue: 7 (2011) Art No: 117

12. Biplob Bhattacherjee, Gautam Bhattacharyya, Sreerup Raychaudhuri, Can flavor physics hint at distinctive signals for R-parity violation at the LHC? Physical Review D84 (2011) Art No: 075006

13. GY Qin, J Ruppert, MG Mustafa, Radiative and collisional jet energy loss in a quark-gluon plasma, Indian Journal of Physics 85 (2011) 873

14. Sanjay K. Ghosh, Tamal K. Mukherjee, Munshi G. Mustafa and Rajarshi Ray, QGP Susceptibilities from PNJL Model, Indian J.Phys. 85 (2011) 87

15.Gautam Bhattacharyya, Heinrich Paes, Daniel Pidt, R-parity violating flavor symmetries, recent neutrino data, and absolute neutrino mass scale, Physical Review D84 (2011) Art No: 113009

16.Harvendra Singh, Super-Yang-Mills and M5-branes, Journal of High Energy Physics, Issue: 8 (2011) Art No: 136

17.Harvendra Singh, Galilean type IIa backgrounds and a map, Modern Physics Letters A26 (2011) 1443

18.Harvendra Singh, Holographic flows to IR Lifshitz spacetimes, Journal of High Energy Physics Issue: 4 (2011) Art No: 118

19.JX Lu, Shibaji Roy, Zhiguang Xiao, Phase structure of black branes in grand canonical ensemble, Journal of High Energy Physics Issue: 5 (2011) Art No: 091

20.JN De, SK Samaddar, Temperature dependence of the symmetry energy of finite nuclei, Physical Review C85 (2012) Art No: 024310

21.JX Lu, Shibaji Roy, Zhiguang Xiao, The enriched phase structure of black branes in canonical ensemble, Nuclear Physics B854 (2012) 913

22.Kumar S Gupta, S Meljanac, A Samsarov, Quantum statistics and noncommutative black holes, Physical Review D85 (2012) Art No: 045029

23.MC Kumar, Prakash Mathews, AA Pankov, N Paver, V Ravindran, AV Tsytrinov, Spin analysis of s-channel diphoton resonances at the LHC, Physical Review D84 (2011) Art No: 115008

24.MC Kumar, Prakash Mathews, V Ravindran, Satyajit Seth, Graviton plus vector boson production to NLO in QCD at the LHC, Nuclear Physics B847 (2011) 54

25.MC Kumar, Prakash Mathews, V Ravindran, Satyajit Seth, Vector boson production in association with KK modes of the ADD model to NLO in QCD at the LHC, Journal of Physics G38 (2011) Art No: 055001

26.Najmul Haque, Munshi G Mustafa, Thoma Markus H, Conserved density fluctuation and temporal correlation function in hard thermal loop perturbation theory, Physical Review D84 (2011) Art No: 054009

27.Najmul Haque Munshi G Mustafa, Quark Number Susceptibility and Thermodynamics in HTL approximation, Nuclear Physics A862 (2011) 271

28.O Ganguly, D Gangopadhyay, P Majumdar, Lorentz-preserving fields in Lorentz-violating theories, EPL 96 (2011) Art No: 61001

29.PG Reinhardi, BK Agrawal, Energy systematics of heavy nuclei-mean field models in comparison, International Journal of Modern Physics E20 (2011) 1379

30.Palash B Pal, Dirac, Majorana, and Weyl fermions, American Journal of Physics 79 (2011) 485

31.Pratyay Banerjee, B Basu-Mallick, Exact solution of DN -type quantum Calogero model through a mapping to free harmonic oscillators, Journal of Mathematical Physics 52 (2011) Art No: 052106

32. Pritibhajan Byakti, Discrete R symmetries and F-term supersymmetry breaking, Physical Review D84 (2011) Art No: 035019

33. Purnendu Chakraborty, Munshi G Mustafa, Markus H Thoma, Screening masses in gluonic plasma, Physical Review D85 (2012) Art No: 056002

34. R Shyam, O Scholten, AW Thomas, Production of a cascade hyperon in the K−proton interaction, Physical Review C84 (2011) Art No: 042201

35. Raktim Abir, Carsten Greiner, Mauricio Martinez, Munshi G Mustafa, Jan Uphoff, Soft gluon emission off a heavy quark revisited, Physical Review D85 (2012) Art No: 054012

36. S Digal, TR Govindarajan, KS Gupta, X Martin, Phase structure of fuzzy black holes, Journal of High Energy Physics, Issue: 1 (2012) Art No: 027

37. SK Samaddar, JN De, Warm α-nucleon matter, Physical Review C83 Art No: 055802

38. S Panda, S Chakraborty, SP Khastgir, Eigenvalue problem in two dimensions for an irregular boundary: Neumann condition, European Physical Journal Plus 126 (2011) Art No: 62

39. Sayan K Chakrabarti, Emmanuel N Saridakis, Anjan A Sen, A new approach to modified gravity models, General Relativity and Gravitation 43 (2011) 3065

40. Sebastian Hollenberg, Octavian Micu, Palash B Pal, Lepton-number violating effects in neutrino oscillations, Physical Review D85 (2012) Art No: 053004

41. Sebastian Hollenberg, Palash B Pal, CPT-violating effects in muon decay, Physics Letters B701 (2011) 89

42. Somdeb Chakraborty, Shibaji Roy, Calculating the jet quenching parameter in the plasma of non-commutative Yang-Mills theory from gauge/gravity duality, Physical Review D85 Art No: 046006

43. Somdeb Chakraborty; Shibaji Roy, Wilson loops in (p+1)-dimensional Yang-Mills theories using gravity/gauge theory correspondence, Nuclear Physics B850 (2011) 463

44. Sovan Chakraborty, Sandhya Choubey, Kamales Kar, On the observability of collective flavor oscillations in diffuse supernova neutrino background, Physics Letters B702 (2011) 209

45. Swapan Majhi, Prakash Mathews, V Ravindran, NNLO QCD corrections to the resonant sneutrino/slepton production at hadron colliders, Nuclear Physics B850 (2011) 287

2012 -13

1. Abhishek Chowdhury, A Harindranath, Jyotirmoy Maiti, Santanu Mondal, Many avatars of the Wilson fermion: a perturbative analysis, J of High Energy Phys 1302 (2013) 037

2. Abhishek Chowdhury, Asit K De, A Harindranath et al, Topological charge density correlator in Lattice QCD with two flavours of unimproved Wilson fermions, Journal of High Energy Physics Issue: 11 (2012) Art No: 029

3. Abhishek Chowdhury, Asit K De, A Harindranath, Jyotirmoy Maiti, Santanu Mondal, Quark mass, scale and volume dependence of topological charge density correlator in Lattice QCD, PoS Lattice 2012 (2012) 200

4. Abhishek Chowdhury, Asit K De, Sangita De Sarkar, A Harindranath, Jyotirmoy Maiti, Santanu Mondal, Anwesa Sarkar, Autocorrelation studies in two-flavour Wilson Lattice QCD using DD-HMC algorithm, PoS Lattice 2012 (2012) 189

5. Abhishek Chowdhury, Asit K De, Sangita De Sarkar, A Harindranath, Jyotirmoy Maiti, Santanu Mondal, Anwesa Sarkar, Low lying hadron spectrum and chiral condensate with two flavors of naive Wilson fermions, PoS Lattice 2012 (2012) 208

6. Anindita Bhattacharjee, Ashok Das, Levi Greenwood et al, Motion of a test particle in the transverse space of Dp-Branes, International Journal of Modern Physics D21 (2012) Art No: 1250056

7. Ashok Das, RR Francisco, J Frenkel, Causal amplitudes in the Schwinger model at finite temperature, Physical Review D86 (2012) Art No. 047702

8. A Sulaksono, BK Agrawal, Existence of hyperons in the pulsar PSRJ1614-2230, Nuclear Physics A895 (2012) 44

9. A Sulaksono, BK Agrawal, Influence of the Effective Mass Modification of Weak Interacting Light Boson on the Properties of Neutron Stars, Few-Body Systems 54 Special Issue: SI (2013) 501

10. Anjan Kundu, Non-holonomic deformation of the DNLS equation for controlling optical soliton in doped fibre media, IMA Journal of Applied Mathematics 77 (2012) 382

11. Baishali Chakraborty, Kumar S Gupta, Siddhartha Sen, Effect of topological defects and Coulomb charge on the low energy quantum dynamics of gapped graphene, Journal of Physics A46 (2013) Art No: 055303

12. B Basu-Mallick, F Finkel, A Gonzalez-Lopez, The exactly solvable spin Sutherland model of B-N type and its related spin chain, Nuclear Physics B866 (2013) 391

13. Bhramar Chatterjee, Amit Ghosh, Near-extremal black holes, Journal of High Energy Physics Issue: 4 (2012) Art No: 125

14. Bhramar Chatterjee, P Mitra, Regularizing tunnelling calculations of Hawking temperature, General Relativity and Gravitation 44(2012) 2365

15. Biswajit Adhikary, Mainak Chakraborty, Ambar Ghosal, Scaling ansatz, four zero Yukawa textures, and large theta(13), Physical Review D86 (2012) Art No:013015

16. Biswajit Adhikary, Probir Roy, Neutrino Yukawa Textures within Type-I Seesaw, ADVANCES IN HIGH ENERGY PHYSICS (2013) Art No:324756

17. BK Agrawal, A Sulaksono, PG Reinhard, Optimization of relativistic mean field model for finite nuclei to neutron star matter, Nuclear Physics A882 (2012) 1

18. BK Agrawal, JN De, SK Samaddar, Determining the Density Content of Symmetry Energy and Neutron Skin: An Empirical Approach, Physical Review Letters 109 (2012) Art No: 262501

19. D Bazeia, Ashok Das, Supersymmetry, shape invariance and the Legendre equations, Physics Letters B715 (2012) 256

20. Debottam Das, Asmaa Abada, Gautam Bhattacharyya, et al, A natural connection between neutrino mass generation and the lightness of a next-to-minimal supersymmetric Standard Model pseudoscalar, Pramana-Journal of Physics 79 (2012) 867

21. Dilip Kumar Ghosh, Probir Roy, Sourov Roy, Four lepton flavor violating signals at the LHC, Journal of High Energy Physics Issue: 5 (2012) Art No:067

22. Gautam Bhattacharyya, Dipankar Das, Palash B Pal, Modified Higgs couplings and unitarity violation, Physical Review D87 (2013) Art No: 011702

23. Gautam Bhattacharyya, Electroweak symmetry breaking beyond the Standard Model, Pramana-Journal of Physics 79 (2012) 675

24. Gautam Bhattacharyya, Ivo de Medeiros Varzielas, Philipp Leser, Common Origin of Fermion Mixing and Geometrical CP Violation, and Its Test Through Higgs Physics at the LHC, Physical Review Letters 109 (2012) Art No: 241603

25. Gautam Bhattacharyya, Philipp Leser, Heinrich Paes, Novel signatures of the Higgs sector from S-3 flavor symmetry, Physical Review D86 (2012) Art No: 036009

26. Gautam Bhattacharyya, Tirtha Sankar Ray, Naturally split supersymmetry, Journal of High Energy Physics Issue: 5 (2012) Art No: 022

27. Gautam Bhattacharyya, Tirtha Sankar Ray, Pushing the SUSY Higgs mass towards 125 GeV with a color adjoint, Physical Review D87 (2013) Art No: 015017

28. Harvendra Singh, Lifshitz/Schrodinger Dp-branes and dynamical exponents, Journal of High Energy Physics Issue: 7 (2012) Art No: 082

29. Harvendra Singh, The Yang-Mills and chiral fields in six dimensions, JHEP 1302 (2013) 056

30. JN De , SK Samaddar, BK Agrawal, Temperature dependence of volume and surface symmetry energy coefficients of nuclei, Physics Letters B716 (2012) 361

31. JN De, SK Samaddar, X Vinas et al, Effects of medium on nuclear properties in multifragmentation, Physical Review C86 92012) Art No: 024606

32. J Piekarewicz, BK Agrawal, G Colo, et al, Electric dipole polarizability and the neutron skin, Physical Review C85 (2012) Art No: 041302

33. Kamales Kar, Statistical spectroscopy for neutron-rich sd-shell nuclei, Journal of Physics G40 (2013)Art No: 015105

34. MC Kumar, Prakash Mathews, V Ravindran, et al, Neutral triple electroweak gauge boson production in the large extra-dimension model at the LHC, Physical Review D85 (2012) Art No: 094507

35. Neelam Guleria, Shashi K Dhiman, Radhey Shyam, A study of Lambda hypernuclei within the Skyrme-Hartree-Fock model, Nuclear Physics A886 (2012) 71

36. Parijat Dey, Shibaji Roy, Holographic entanglement entropy of the near horizon 1/4 BPS F-Dp bound states, Physical Review D87(2013) Art No: 066001

37. Parijat Dey, Shibaji Roy, Intersecting D-branes and Lifshitz-like space-time, Physical Review D86 (2012) Art No: 066009

38. Parijat Dey, Shibaji Roy, Lifshitz-like space-time from intersecting branes in string/M theory, Journal of High Energy Physics Issue: 6 (2012) Art No: 129

39. Parijat Dey, Shibaji Roy, Lifshitz metric with hyperscaling violation from NS5-Dp states in string theory, Phys Lett B720(2013) 419 P Mitra, Area law for black hole entropy in the SU(2) quantum geometry approach, Physical Review D85 (2012) Art No: 104025

40. P Mitra, Zeta function regularization, anomaly and complex mass term, European Physical Journal C72 (2012) Art No: 2024

41. Pratyay Banerjee, B Basu-Mallick, Level density distribution for one-dimensional vertex models related to Haldane-Shastry like spin chains, Journal of Mathematical Physics 53 (2012) Art No: 083301

42. Purnendu Chakraborty, Munshi G Mustafa, D=2 gluon condensate and QCD propagators at finite temperature, Physics Letters B711 (2012) 390

43. Raktim Abir, Jet-parton inelastic interaction beyond eikonal approximation, Physical Review D87 Art No: 034036

44. Raktim Abir, Umme Jamil, Munshi G Mustafa et al, Heavy quark energy loss and D-mesons in RHIC and LHC energies, Physics Letters B715 (2012) 183

45. R Frederix, Manoj K Mandal, Prakash Mathews, et al, Diphoton production in the ADD model to NLO plus parton shower accuracy at the LHC, Journal of High Energy Physics Issue: 12 (2012) Art No: 102

46. R Shyam, K Tsushima, AW Thomas, Production of cascade hypernuclei via the (K-, K+) reaction within a quark-meson coupling model, Nuclear Physics A881 (2012) 255

47. Rudranil Basu, Ayan Chatterjee, Amit Ghosh, Local symmetries of non-expanding horizons, Classical and Quantum Gravity 29 (2012) Art No: 235010

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

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25. Aritra Bandyopadhyay, Chowdhury Aminul Islam and Munshi G. Mustafa, Electromagnetic spectral properties and Debye screening of a strongly magnetized hot medium,, Phys. Rev. D94 (2016) no.11, 114034

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Books authored by Theory Division members in this period

• *An introductory course of Particle Physics*
Palash B Pal
800+ pages. CRC Press, July 2014

• *Symmetry and Symmetry Breaking in Quantum Field Theory*
Parthasarathi Mitra
112 pages. CRC Press, May 2014

• *Many-Body Physics, Topology and Geometry*
Siddhartha Sen and Kumar S. Gupta
219 pages, World Scientific, June 2015

Arnab Kundu, Associate Professor E

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Education

2010: Ph.D, Physics, University of Southern California, Los Angeles, USA
2004: M.Sc, Physics, Indian Institute of Technology, Kanpur, India
2002: B.Sc, Physics, Jadavpur University, Kolkata, India

Academic Positions

2013 - : Associate Professor E, Saha Institute of Nuclear Physics, Kolkata, India
2013 - 2014: Visiting Fellow, Gravitation and Cosmology Group, University of Barcelona, Spain
2010 - 2013: Simons Fellow, Weinberg Theory Group, University of Texas, Austin, USA

Awards / Honours

Simons Foundation Participant, Aspen Centre for Physics (2014)
Simons Postdoctoral Fellowship, Simons Foundation, USA (2010 - 2013)
Graduate Fellowship, University of Southern California (Summer, 2006 - 2010)
Notional Award and Certificate of Merit by IIT Kanpur (2002-2003)

Selected Publications

"Oscillating Shells and Oscillating Balls in AdS." Avik Banerjee, Arnab Kundu, Pratik Roy, Amitabh Virmani. *JHEP 1706 (2017).* e-Print Archive: *arXiv: 1704.07570 [hep-th].*

"Fundamental Flavours, Fields and Fixed Points: A Brief Account" Arnab Kundu, Nilay Kundu. *JHEP 1703 (2017) 071.* e-Print Archive: *arXiv: 1612.08624 [hep-th].*

"Emergent Horizons and Causal Structures in Holography." Avik Banerjee, Arnab Kundu, Sandipan Kundu. *JHEP 1609 (2016) 166.* e-Print Archive: *arXiv: 1605.07368 [hep-th].*

"Flavour Fields in Steady State: Stress Tensor and Free Energy" Avik Banerjee, Arnab Kundu, Sandipan Kundu. *JHEP 1602 (2016) 102.* e-Print Archive: *arXiv: 1512.05472 [hep-th].*

"Three-dimensional super Yang-Mills with compressible quark matter." Anton Faedo, Arnab Kundu, David Mateos, Christiana Pantelidou, Javier Tarrio. *JHEP 1603 (2016) 154.* e-Print Archive: *arXiv: 1511.05484 [hep-th].*

"Effective Temperature in Steady-state Dynamics from Holography." Arnab Kundu. *JHEP 1509 (2015) 042.* e-Print Archive: *arXiv: 1507.00818 [hep-th]*

"Weak Field Collapse in AdS: Introducing a Charge Density." Elena Caceres, Arnab Kundu, Juan Pedraza, Di-Lun Yang. *JHEP 1506 (2015) 111.* e-Print Archive: *1404.1570 [hep-th].*

"(Super)Yang-Mills at Finite Heavy-Quark Density." Anton Faedo, Arnab Kundu, David Mateos, Javier Tarrio. *JHEP 1502 (2015) 010 .* e-Print Archive: *arXiv: 1410.4466 [hep-th].*

"Steady-state Physics, Effective Temperature Dynamics in Holography." Arnab Kundu, Sandipan Kundu. *Phys.Rev.D. D91 (2015) no.4, 046004.* e-Print Archive: *arXiv: 1307.6607 [hep-th].*

"Holographic Entanglement in a Noncommutative Gauge Theory." Willy Fischler, Arnab Kundu, Sandipan Kundu. *JHEP 1401 (2014) 137.* e-Print Archive: *arXiv: 1307.2932 [hep-th].*

"Dynamics of Non-supersymmetric Flavours." M. Sohaib Alam, Matthias Ihl, Arnab Kundu, Sandipan Kundu. *JHEP 1309 (2013) 130.* e-Print Archive: *arXiv: 1306.2178 [hep-th].*

"Strong Subadditivity, Null Energy Condition and Charged Black Holes." Elena Caceres, Arnab Kundu, Juan Pedraza, Walter Tangarife. *JHEP 1401 (2014) 084.* e-Print Archive: *arXiv: 1304.3398 [hep-th].*

"Jet Quenching and Holographic Thermalization with a Chemical Potential." Elena Caceres, Arnab Kundu, Di-Lun Yang. *JHEP 1403 (2014) 073.* e-Print Archive: *arXiv: 1212.5728 [hep-th].*

"Holographic Mutual Information at Finite Temperature." Willy Fischler, Arnab Kundu, Sandipan Kundu. *Phys.Rev. D87 (2013) no.12, 126012.* e-Print Archive: *arXiv: 1212.4764 [hep-th].*

"Back-reaction of Non-supersymmetric Probes: Phase Transition and Stability." Matthias Ihl, Arnab Kundu, Sandipan Kundu. *JHEP 1212 (2012) 070.* e-Print Archive: *arXiv: 1208.2663 [hep-th].*

"Holographic Thermalization with Chemical Potential." Elena Caceres, Arnab Kundu. *JHEP 1209 (2012) 055.* e-Print Archive: *arXiv: 1205.2354 [hep-th].*

"Chiral Symmetry Breaking and External Fields in the Kuperstein-Sonnenschein Model." M. Sohaib Alam, Vadim Kaplunovsky, Arnab Kundu. *JHEP 1204 (2012) 111.* e-Print Archive: *arXiv: 1202.3488 [hep-th].*

"Minimal Holographic Superconductors from Maximal Supergravity." Nikolay Bobev, Arnab Kundu, Krzysztof Pilch, Nicholas Warner. *JHEP 1203 (2012) 064 .* e-Print Archive: *arXiv: 1110.3454 [hep-th].*

Teaching / Guidance

Supervising two PhD students, Avik Banerjee and Augniva Ray
Since 2014 taught three advanced courses at SINP: Quantum Field Theory II (2015), Conformal Field Theory (2016), Topics in String Theory and Quantum Field Theory (2017)
Invited Lecture Series in SYK Models & Black Hole Physics, IACS, Kolkata (February, 2017)
Invited Lecture Series on Fundamental Flavours, Veneziano Limit & Holography, HRI, Allahabad (November-December, 2016)

Areas of Research

Gauge-string Duality and strongly coupled systems, String Theory, Quantum Field Theory, Quantum Gravity

Essential Strength of Research:

For the period of 2012-present, my research interests have revolved around using Gauge-String Duality to address strongly coupled problems. I have broadly been interested in three categories of problems in this regard: (i) Strongly coupled systems at non-vanishing density, (ii) Dynamical questions in strongly coupled systems, and (iii) Condensed matter inspired problems in Holography. Within the above themes, I have primarily worked on identifying and constructing potential infra-red description for matter with non-vanishing density, consisting of both adjoint and fundamental degrees of freedom, within Gauge-String duality. I have analyzed dynamical issues, such as thermalization in strongly coupled systems and the evolution of entanglement entropy in such, by studying various time-dependent configurations in AdS-geometry. Finally, I have also worked on constructing condensed-matter-inspired models within the AdS/CFT correspondence, such as the analogues of holographic superconductors.

Future Research Plan:

My future plans, broadly speaking, have two components. One in which I would like to continue exploring various aspects of strongly coupled dynamics in the context of Gauge-String duality, including, but not limited to, the areas mentioned above. For example, I would like to pursue an understanding of the so-called colour-flavour locked phase in a suitable strongly coupled gauge theory, in the context of holography. Intriguingly, this may be connected to models in which emergence of space-time may be natural. I would like to explore this connection in more details. In the other part, I would like to explore the recently-revived SYK-type large N models, which seems intimately related to the understanding of holography in low-dimensions. In brief, for future, I am interested in studying various issues of large N theories, and their connections with Holography.

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Education

2007: Ph.D, Physics, University of Massachusetts, Amherst, USA
2002: M.Sc, Physics, Indian Institute of Technology, Kanpur, India
1997: B.Sc, Physics, Jadavpur University, Kolkata, India

Academic Positions

2013 - : Associate Professor E, Saha Institute of Nuclear Physics
2012 - 2013: Assistant Professor, Indian Institute of Science Education and Research, Bhopal
2010 - 2012: Postdoctoral Research Assistant, DESY, Hamburg, Germany
2007 - 2010: Postdoctoral Research Fellow, Max-Planck-Institut für Physik, Munich, Germany

Awards / Honours

Junior Scientific Associateship, ICTP, Trieste, Italy (2014 - 2019)
Max Planck Society - DST Visiting Fellowship (2013 - 2017)
Ramanujan Fellowship, Department of Science and Technology, Govt. of India (2012 - 2017)
Received MAPCOST Popular Science Grant (along with IISER, Bhopal Science Club), 2012

Areas of Research

Inflationary cosmology and its connections to particle physics, Confronting cosmological models with data, Dark energy

Selected Publications

"Supergravity Contributions to Inflation in models with non-minimal coupling to gravity." Kumar Das, Valerie Domcke, Koushik Dutta. *JCAP 1703 (2017) no.03, 036.* e-Print arXiv: *1612.07075 [hep-ph].*

"Moduli Vacuum Misalignment and Precise Predictions in String Inflation." Michele Cicoli, Koushik Dutta, Anshuman Maharana, Fernando Quevedo *JCAP 1608 (2016) no.08, 006.* e-Print: *arXiv:1604.08512 [hep-th]*

"Inflationary Predictions and Moduli Masses." Kumar Das, Koushik Dutta, Anshuman Maharana *Phys.Lett. B751 (2015) 195-200* . e-Print: *arXiv:1506.05745 [hep-ph]*

"Curvature Singularity in $f(R)$ Theories of Gravity." Koushik Dutta, Sukanta Panda, Avani Patel *Phys.Rev. D92 (2015) 6, 063503* . e-Print: *arXiv:1504.05790 [gr-qc]*

"N-flation with Hierarchically Light Axions in String Compactifications." Michele Cicoli, Koushik Dutta, Anshuman Maharana *JCAP 1408 (2014) 012* . e-Print: *arXiv:1401.2579 [hep-th]*

"The Overshoot Problem in Inflation after Tunneling." Koushik Dutta, Pascal M. Vaudrevange, Alexander Westphal *JCAP 1201 (2012) 026.* e-Print: *arXiv:1109.5182 [hep-th]*

"Cosmology of Horava-Lifshitz f(R) Gravity." Sayan K. Chakrabarti, Koushik Dutta, Anjan A. Sen. *Phys.Lett. B711 (2012) 147-152.* e-Print: *arXiv:1108.2781 [astro-ph.CO]*

"Combining High-scale Inflation with Low-energy SUSY." Stefan Antusch, Koushik Dutta, Sebastian Halter. *JHEP 1203 (2012) 105.* e-Print: *arXiv:1112.4488 [hep-th].*

"Likely values of the Higgs vev." John F. Donoghue, Koushik Dutta, Andreas Ross, Max Tegmark *Phys.Rev.D 81:073003,2010.* e-Print: *arXiv:0903.1024 [hep-ph]*

"Solving the eta-Problem in Hybrid Inflation with Heisenberg Symmetry and Stabilized Modulus." Stefan Antusch, Mar Bastero-Gil, Koushik Dutta, Steve F. King, Philipp M. Kostka *JCAP 0901:040,(2009).* e-Print: *arXiv:0808.2425 [hep-ph]*

"Non-isotropy in the CMB power spectrum in single field inflation." John F. Donoghue, Koushik Dutta, Andreas Ross *Phys.Rev.D80:023526,(2009).* e-Print: *arXiv:astro-ph/0703455*

"Confronting pNGB quintessence with data." Koushik Dutta, Lorenzo Sorbo *Phys.Rev.D75:063514,(2007).* e-Print: *arXiv:astro-ph/0612457*

Teaching / Guidance

Supervising Ph.D thesis of two students, and one is expected to submit thesis by July, 2017
Taught regularly in SINP graduate courses
Tutor for SERC Preparatory School on Theoretical High Energy Physics, September 2016
Invited Lecture Series in Winter School in Cosmology, ISI, Kolkata, January, 2016

Essential Strength of Research: In recent years, I have focussed my research in the following areas:

Relating post-inflationary history of the Universe with inflationary observables: The predictions for all the cosmological observables of any inflationary model depend on the number of e-foldings during inflation which is sensitive to the post-inflationary history of the universe. In physics beyond the standard model (Supergravity / String Theory), the generic presence of gravitationally coupled light scalar fields (e.g moduli in String Theory) 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. In a series of works, we have explored this effect in detail, and found that understanding the details of post-inflationary physics including reheating is crucial for future precision measurements of scalar spectral index n_s with projected sensitivity of $\Delta n_s \sim 0.001$.

Aspects of inflation model building in supergravity and String Theory: From the point of view of physics beyond the Standard Model, the existence of multiple scalar fields is very natural, and it is expected generically that in addition to the usual inflaton, many other fields would also be shifted away from their global minimum. In that case, a collective motion of several scalar fields can drive inflation. We have worked on embedding this idea in supergravity and type IIB String Theory. Additionally, we have investigated non-thermal gravitino production after tribrid inflation in supergravity, which is a variant of supersymmetric hybrid inflation where three fields are involved and where the inflaton field resides in the matter sector of the theory. We have found that the non-thermal gravitino problem is generically absent in models of tribrid inflation. We have also systematically studied the supergravity contributions relevant for inflationary model building in a Jordan frame. In this framework, canonical kinetic terms in the Jordan frame result in the separation of the Jordan frame scalar potential into a tree-level term and a supergravity contribution, which is potentially dangerous for sustaining inflation. We have shown that if the vacuum energy necessary for driving inflation originates dominantly from the F-term of an auxiliary field (i.e. not the inflaton), the supergravity corrections to the Jordan frame scalar potential are generically suppressed.

Phenomenology of modified gravity theories: Although $f(R)$ modification of late time cosmology is successful in explaining present cosmic acceleration, it is difficult to satisfy the fifth-force constraint simultaneously. Even when the fifth-force constraint is satisfied, the effective scalar degree of freedom may move to a point (close to its potential minima) in the field space where the Ricci scalar diverges. We have elucidated this point further with a specific example of $f(R)$ gravity that incorporates several viable $f(R)$ gravity models in the literature. In particular, we have shown that the nonlinear evolution of the scalar field in pressureless contracting dust can easily lead to the curvature singularity, making this theory unviable. Recently, we have also worked on inflationary attractor models in the context of scalar-tensor theories.

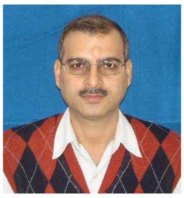
Future Research Plan: In future, I would like to focus on the following areas:

Probing post-inflationary history of the Universe: The Universe could be matter dominated all the way up to MeV energy scale. In future, I would like to find a strategy in probing this epoch further. In particular, I would like to understand how this non-standard epoch may change the formation of cosmological structures, and affect the future CMB distortion maps.

Production of gravitational wave during/after inflation: The amplitude of gravitational wave produced during inflation is parametrised by the observable tensor-to-scalar ratio r. The CMB measurements have an upper limit of $r < 0.11$. But, in the presence of non-canonical terms like Chern-Simons term or $\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$ in the Lagrangian, the production of gravitational wave is changed considerably. Additionally, the existence of other light scalar fields can modify the gravitational wave production at the end of inflation. I would like to explore this aspects and related areas in recent future.

Constraining inflation model using data: I would like to use the latest CMB and other cosmological data in constraining inflation models those are motivated from particle physics. The work is in progress in constraining models of warm inflation, and the scenario of open inflation.

Academic Review 2012-2017



Name: Prof. Harvendra Singh **Present Position** : Professor 'G'
Date of Birth: 15.08.1969 **Qualification**: Ph.D. (IOP Bhubaneswar/Utkal University)
E-mail: h.singh@saha.ac.in

I) Permanent positions held:

- Professor E F & G, at SINP, Kolkata, since January 2005 - till now
- Assistant Professor, at IIT, Guwahati, July/2003 - January/2005

II) Recent Visits:

- Associateship visit , to the ICTP, Trieste, during 01/Oct - 10/Dec/2016. Also visited the Arnold Sommerfeld Center, LMU, Munich and the INFN/University of Padova.
- Associate visit, to the ICTP, Trieste, during 23/Sep - 26/Oct/2013. Also made a short visit to ASC, LMU, Munich.

III) Awards and Honours :

University Gold Medal (1989), L.K. Panda Fellowship Award (1992) INFN Fellow Italy (1997-99), Alexander-von-Humboldt Fellow Germany (2000-02), Junior Associateship ICTP, Trieste (2004-20011), Regular Associateship ICTP, Trieste (2012-2017)

IV) Teaching/Guidance:

- I have offered Post-M.Sc. level courses such as QFT I & II, and String Theory at SINP. I was a tutor for "Large N Field Theory" course in XXVII SERC School (2012).
- I am guiding a research student (R. Mishra) and he would be finishing Ph.D. by July 2018.

V) Important publications since last review:

1. Harvendra Singh, "D2-D8 system with massive strings and the Lifshitz spacetimes," JHEP **1704**, 011 (2017) [arXiv:1701.00968 [hep-th]].
2. Rohit Mishra and Harvendra Singh, "Perturbative entanglement thermodynamics for AdS spacetime: Renormalization," JHEP **1510**, 129 (2015) [arXiv:1507.03836 [hep-th]].
3. Harvendra Singh, "Lifshitz to AdS flow with interpolating p-brane solutions," JHEP **1308**, 097 (2013) [arXiv:1305.3784 [hep-th]].
4. Harvendra Singh, "Lifshitz/Schródinger Dp-branes and dynamical exponents," JHEP **1207**, 082 (2012) [arXiv:1202.6533 [hep-th]].
5. Harvendra Singh, "Super-Yang-Mills and M5-branes," JHEP **1108**, 136 (2011) [arXiv: 1107.3408 [hep-th]].

6. Harvendra Singh "Special limits and non-relativistic solutions," JHEP **1012**, 061 (2010) [arXiv: 1009.0651 [hep-th]].

Summary of Research Output:

Areas: String Theory, Super-gravity

In AdS/CFT holography, recently the Lifshitz vacua with broken Lorentzian symmetry, have become useful tool to study critical phenomenon in the boundary nonrelativistic theory. We have obtained new supersymmetric Lifshitz vacua, $Lif^{z=3}$, having dynamical exponent $z = 3$ in type IIB string theory, and the $Lif^{z=\frac{5}{2}}$ Lifshitz vacua of 11-dimensional M-theory. The former vacua can also be recognised as $z = 3$ and $\theta = 1$ 'hyperscaling' Lifshitz vacua in four dimensions, but only after explicit dimensional reduction to $4D$. Various IR properties and Lifshitz to AdS RG-flows of such solutions have also been studied by us subsequently. Our solutions describe RG flow from $z = 3, \theta = 1$ $4D$ Lifshitz fixed point in IR to a $z = 1, \theta = -1$ relativistic geometry in the UV. Very recently in JHEP1704, we have successfuly embedded the much known $4D$ Lifshitz $z = 2$ vacua of Einstein-Proca model in 10-dimensional massive Romans supergravity. The corresponding $10D$ solution is now described as $Lif_4^{z=2} \times S^1 \times S^5$. It is constituted by $D2 - D8$ branes which are nested with 'massive' string field. The knowledge of 10-dimensional embeddings is crucial from the point of view of understanding Lifshitz holography where string like excitations could be realised in the boundary $4D$ nonrelativitic theory.

We have also calculated the entanglement entropy for CFT subsystems (mainly strip subsystems) on the boundary of the 'boosted' AdS_{d+1} black branes. No calculations existed beyond the first order for strip subsystems, whereas we have done our calculations using 'perturbative' methods upto second order analytically. We also needed to renormalize (redefine) the thermodynamic quantities, such as 'entanglement temperature' (length) and chemical potential etc so that the first law can exist. We have also studied holgraphic theory describing M5 branes. We found that the known $5D$ super-Yang-Mills theory of D4 branes can be lifted to $6D$ by introducing an auxiliary Abelian vector field. Remarkably, the equations of motion of the theory describe self-dual interacting non-abelian tensor fields, $H_3 = *H_3$.

Brief Future Plan

The future research plan will be based on the continuation of the ongoing projects. Recently, the Lifshitz and Schrödinger type vacua with broken Lorentzian symmetry, were construted. These have become useful to holographically study strongly coupled critical phenomenon in the boundary nonrelativistic theory. It will be worthwhile to further study the Lifshitz vacua $Lif_4^{z=2} \times S^1 \times S^5$ and its T-dual vacua and explore dual field theory. These are constituted mainly by $D2 - D8$ or $D0 - D6$ branes nested with 'massive' B field. The massive string like extended excitations can be realised in respective nonrelativitic boundary theories.

Further the calculations of entanglement entropy for CFT subsystems (strip or sphecrical) on the boundary of 'boosted' AdS_{d+1} black holes can be extended to include systems where the subsystem itself lies along the boost direction. This is needed to study the velocity effects on the entanglement entropy of the small subsystems. No calculations exist beyond first order for such subsystems. We plan to study entanglement entropy for the Lifshitz solutions too. Certainly, a new supersymmetric holgraphic $6D$ theory describing M5-branes on $AdS_7 \times S^4$ is yet to be constructed. The theory presumably should be written in terms of self-dual interacting tensor fields. Interestingly, the question can be asked whether known string-like extended instanton solutions, supported by self-dual $2D$ axionic scalar and $4D$ YM gauge instantons, could be constituted by the tensor fields in such a theory.

Amit Ghosh, Professor G

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Education
1997: Ph.D, Physics, Jadavpur University
1991: M.Sc, Physics, University of Calcutta

Academic Positions
2002 - : Saha Institute of Nuclear Physics
1999 - 2002: Postdoctoral Fellow, Center for Geometry and Gravitational Physics, Penn State Univ, USA
1997 - 1999: John Bell Fellow, CERN, Theory Division, Switzerland

Selected Publications

CFT/Gravity Correspondence on the Isolated Horizon: Amit Ghosh (Saha Inst), Daniele Pranzetti (Erlangen Nuremberg U). *Nucl. Phys. B889 (2014) 1-24.*

Statistics, holography, and black hole entropy in loop quantum gravity: Amit Ghosh (Saha Inst), Karim Noui (Tours U, CNRS & Fed. Denis Poisson, Tours & APC, Paris), Alejandro Perez (Marseille, CPT & Toulon U.). *Phys. Rev. D89 (2014) no.8, 084069.*

Entropy from near-horizon geometries of Killing horizons: Olaf Dreyer (Rome U.& INFN, Rome), Amit Ghosh, Avirup Ghosh (Saha Inst.). *Phys. Rev. D89 (2014) no.2, 024035.*

Hawking radiation from dynamical horizons: Ayan Chatterjee (Tata Inst.), Bhramar Chatterjee, Amit Ghosh (Saha Inst.). *Phys. Rev. D87 (2013) no.8, 084051.*

Near-extremal black holes: Bhramar Chatterjee, Amit Ghosh (Saha Inst.). *JHEP 1204 (2012) 125.*

Quasilocal first law for black hole thermodynamics: Ernesto Frodden (Chile U., Catolica & Marseille, CPT), Amit Ghosh (Saha Inst.), Alejandro Perez (Marseille, CPT). *Phys. Rev. D87 (2013) no.12, 121503.*

Black hole entropy and isolated horizons thermodynamics: Amit Ghosh (Saha Inst.), Alejandro Perez (Marseille, CPT & Sud Toulon Var U.). *Phys. Rev. Lett. 107 (2011) 241301, Erratum: Phys. Rev. Lett. 108 (2012) 169901.*

Quantum and classical areas of black hole thermodynamics: A. Ghosh, P. Mitra. *Class. Quant. Grav. 32 (2015) no.16, 165006.*

Absence of log correction in entropy of large black holes: A. Ghosh, P. Mitra. *Phys. Lett. B734 (2014) 49-51.*

Teaching / Guidance
Two students (Atanu Kumar and Avirup Ghosh) have been awarded PhD degrees in 2016. Atanu is now teaching in a Govt College, WB and Avirup is doing post-doc at IIT, Gandhinagar.
Taught regularly in pre-PhD courses

Areas of Research
Quantum Physics around black holes, Classical gravity

Essential Strength of Research:

NP B889 (2014) 1-24: A quantum isolated horizon can be modeled by an $SU(2) \times SU(2)$ Chern-Simons theory on a punctured two-sphere. By means of the isolated horizon boundary conditions, it is shown how a two-dimensional conformal symmetry arises at each puncture inducing an infinite set of new observables localized at the horizon which satisfy a Kac-Moody algebra.

PR D89 (2014) no.8, 084069: In loop quantum gravity the quantum states of a black hole horizon consist of pointlike discrete quantum geometry excitations called punctures that are labeled by spin j, $j = 1/2, 1, ...$ The excitations possibly carry other internal degrees of freedom, and the associated quantum states are eigenstates of the area operator. The appropriately scaled area operator A/l can also be interpreted as the physical Hamiltonian associated with the quasilocal stationary observers located at a small distance l from the horizon. It follows that: Up to quantum corrections, matter degrees of freedom saturate the holographic bound. Up to quantum corrections, the statistical black hole entropy coincides with Bekenstein-Hawking entropy.

In PR D89 (2014) no 2, 024035, we derived the Bekenstein-Hawking entropy for black holes based on the near-horizon symmetries of black hole space-times.

In PR D87 (2013) no 8, 084051, in completely local settings, we established that a spherically symmetric, dynamically evolving black hole horizon can be assigned a Hawking temperature under a mild assumption. Moreover, we calculate the Hawking flux and show that the radius of the horizon shrinks in accordance with the amount of emitted flux.

In JHEP 1204 (2012) 125, we presented a new formulation of deriving Hawking temperature for near-extremal black holes using distributions. In this paper the near-extremal Reissner-Nordström and Kerr black holes are discussed. It is shown that the extremal solution as a limit of non-extremal metric is well-defined. The pure extremal case is also discussed separately.

In PR D87 (2013) no 12, 121503, we first show that stationary black holes satisfy an extremely simple quasilocal form of the first law, $\delta E = (\tilde{\kappa}/8\pi)\delta A$, where the (quasilocal) energy $E = A/(8\pi l)$ and (local) surface gravity $\tilde{\kappa} = 1/l$, with A is the horizon area and l is a proper length characterizing the distance to the horizon of a preferred family of quasilocal observers suitable for thermodynamical considerations. Our construction is extended to the more general framework of isolated horizons. The local surface gravity is universal. This has important implications for semiclassical considerations of black hole physics as well as for the fundamental quantum description arising in the context of loop quantum gravity.

In PRL 107 (2011) 241301, we made a statistical mechanical calculation of the thermodynamical properties of nonrotating isolated horizons. The introduction of Planck scale allows for the definition of a universal horizon temperature (independent of the mass of the black hole) and a well-defined notion of energy (as measured by suitable local observers) proportional to the horizon area in Planck units. The microcanonical and canonical ensembles associated with the system are introduced. Black hole entropy and other thermodynamical quantities can be consistently computed in both ensembles and results are in agreement with Hawkings semiclassical analysis for all values of the Immirzi parameter.

Most calculations of black hole entropy in loop quantum gravity indicate a term proportional to the area eigenvalue A with a correction involving the logarithm of A. This violates the additivity of entropy. In CQG 32 (2015) no 16, 165006, an entropy proportional to A, with a correction term involving the logarithm of the classical area k, which is consistent with the additivity of entropy, is derived in both U(1) and SU(2) formulations. In PL B734 (2014) 49, we find that the calculations yield an entropy proportional to the area eigenvalue with no such correction if the ChernSimons level is finite, so that the area eigenvalue can be relatively large.

Future Research Plan:

(1) Investigate alternative theories of gravity: An attempt will be made to modify Einstein's theory so that gravity is modified at short distances and behaves like a usual gauge theory, but at large distances it is described by Einstein's theory (to be consistent with observations). Such models may be more susceptible to quantization because a gauge theory is controlled by a dimensionless coupling.

(2) Exact Hilbert spaces for Hilbert theories: Some low dimensional integrable systems and also some in higher dimensions show that nonperturbative Hilbert spaces are very different from the Fock space. This is understandably so because of some general theorems found earlier in field theories that limits the use of Fock spaces to free systems only. Yet Fock space is very successful in describing almost-free field theories and in a large number of observations. However, the question remains whether these perturbative corrections converge to some exact Hilbert space. This issue will be investigated further in the context of some exactly solvable field theories and attempts will be made to find a Hilbert space beyond the perturbative Fock space.

Gautam Bhattacharyya, Senior Professor H+

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Education
1993: Ph.D, Physics, Calcutta University
1989: M.Sc, Physics, Calcutta University

Academic Positions
Faculty (SINP): Currently, Senior Professor 'H+', Joined as Reader 'D' in Jan 1998.
Postdocs: INFN, Pisa, Italy (1996-97); CERN Theory Division, Geneva (1994-95).

Awards / Honours
J.C. Bose National Fellowship (2017-); FASc (2015); FNASc (2013); FNA (2013); B.M. Birla Science Prize in Physics (2005); Adjunct Faculty of TIFR (2009-12, 2015-17); SFB Full Professor visitorship at DESY, Hamburg (2015); Mercator Visiting Professor (DFG) at Dortmund (2012); Paid Scientific Associateship at CERN (2007), Regular Associateship of ICTP (1998-2005).

One review article and 10 selected papers

Selected Publications

1. A Pedagogical Review of Electroweak Symmetry Breaking Scenarios, G. Bhattacharyya, Rept. Prog. Phys. 74 (2011) 026201 [arXiv:0910.5095 [hep-ph]], based on lectures in (main) SERC School in Theoretical High Energy Physics at Hyderabad 2007, RECAPP workshop at HRI 2008, and Vietnam School 2009.
2. Nondecoupling of charged scalars in Higgs decay to two photons and symmetries of the scalar potential, G. Bhattacharyya and D. Das, Phys. Rev. D 91 (2015) 015005 (7 pages) [arXiv:1408.6133 [hep-ph]].
3. A common origin of fermion mixing and geometrical CP violation, and its test through Higgs physics at the LHC, G. Bhattacharyya, I. de Medeiros Varzielas and P. Leser, Phys. Rev. Lett. 109 (2012) 241603 [arXiv:1210.0545 [hep-ph]].
4. A phenomenological study of 5d supersymmetry, G. Bhattacharyya and T.S. Ray, JHEP 05 (2010) 040 [arXiv:1003.1276 [hep-ph]].
5. Probing Universal Extra Dimension at the International Linear Collider, G. Bhattacharyya, P. Dey, A. Kundu and A. Raychaudhuri, Phys. Lett. B 628 (2005) 141-147 [hep-ph/0502031].
6. Effects of R-parity violation on direct CP violation in B decays and extraction of γ, G. Bhattacharyya and A. Datta, Phys. Rev. Lett. 83 (1999) 2300-2303 [hep-ph/9903490].
7. Naturalness constraints on gauge mediated supersymmetry breaking models; G. Bhattacharyya and A. Romanino, Phys. Rev. D 55 (1997) 7015-7019 [hep-ph/9611243].
8. New LEP bounds on B-violating scalar couplings: R-parity violating supersymmetry or diquarks; G. Bhattacharyya, D. Choudhury and K. Sridhar, Phys. Lett. B 355 (1995) 193-198 [hep-ph/9504314].
9. New LEP constraints on some supersymmetric Yukawa interactions that violate R-parity; G. Bhattacharyya, J. Ellis and K. Sridhar, Mod. Phys. Lett. A 10 (1995) 1583-1592 [hep-ph/9503264].
10. Oblique electroweak corrections and new physics; G. Bhattacharyya, S. Banerjee and P. Roy, Phys. Rev. D 45 (1992) 729-733, Rapid Communication; Erratum- ibid. D 46 (1992) 3215.
11. Z decay confronts nonstandard scenarios; G. Bhattacharyya, A. Raychaudhuri, A. Datta and S.N. Ganguli, Phys. Rev. Lett. 64 (1990) 2870-2873.

Teaching / Guidance

Taught in 7 SERC Schools, and Vietnam international School (2009).

1. **Avik Banerjee** (CSIR S.P.M. Fellowship winner): Joined Aug 2016 (Working on Composite Higgs).
2. **Dipankar Das**: 2011-15 (Ph.D. 2015)
   Thesis: *Implications of the Higgs discovery on Physics beyond the Standard Model*
   Postdoc: Valencia, Spain 2015-17.
   Permanent Job: Dept. of Physics, University of Calcutta (2017 -).
3. **Kalyan Brata Chatterjee**: 2005-10 (Ph.D. 2014)
   Thesis: *Some implications of R-parity violation in Supersymmetry*
   Permanent Jobs: Derozio Memorial College, Kolkata (2010-16); R.K Mission Vivekananda Centenary College, Rahara (2016 -).
4. **Tirtha Sankar Ray** (CSIR S.P.M. Fellow): 2006-10 (Ph.D. 2010)
   Thesis: *Beyond the Standard Model: Some aspects of Supersymmetry and Extra dimension*
   Postdocs: Saclay, France 2010-12; Melbourne, Australia 2012-14.
   Permanent Job: Dept. of Physics, IIT-Kharagpur (2014 -).
5. **Paramita Dey**: 2001-05 (Ph.D. 2006)
   Thesis: *Some phenomenological aspects of extra dimensional models*
   Postdocs: Orsay, France 2005-06; HRI, India 2006-09; Aachen, Germany 2009-13.

Essential Strength of Research: Phenomenology of the Standard Model and beyond (e.g., Supersymmetry, Extra Dimensions, Little Higgs, Composite Higgs); Neutrino and Flavor Physics and their interplay with Collider results.

Future Research Plan:

Probing Physics Beyond the Standard Model from an interplay between accelerator and non-accelerator data. More specifically, exploring the parameter space of BSM physics using data from Higgs production and decays at LHC, flavor-physics oriented experiments, as well as cosmology.

Service to community:

1. Governing Council Member, Inter-University Accelerator Centre, New Delhi (2016-18).
2. 'Special invited expert' in the PAC meeting on 'Physical Sciences' of SERB, DST (2016,'17). 'PAC member' of SERB, DST, for evaluation of R&D proposals in 'Plasma, High Energy, Nuclear Physics, Astronomy & Astrophysics and Nonlinear Dynamics' for the 3 year cycle (2012-15).
3. 'Task Force Member' of SERB, DST, Committee on 'Empowerment and Equity Opportunities for Excellence in Science (EMEQ)' for evaluation of R&D proposals of SC/ST candidates (2016-17).
4. Member of the 'Planning Committee of SERC School' on 'Theoretical High Energy Physics', sponsored by DST, Govt. of India, for the VI^{th} cycle (2010-15) and VII^{th} cycle (2016-20).
5. Member of expert panel of 'Odisha Science Aademy' for selection of Biju Patnaik Award, Samanta Chandra Sekhar Award and Odisha Young Scientist Award (2016,'17).
6. Member of the 'Program Committee' of ICTS, TIFR (2010-12).
7. International Advisory Board: Workshop Series on 'Flavor Symmetries (FLASY)'.
8. Convener: XVIth DAE-BRNS High Energy Physics Symposium, SINP, 29 Nov - 3 Dec, 2004.
9. Working Group Coordination and Conference Organizing Committee: **Many**

Bijay Kumar Agrawal, Professor H

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Education

1996: Ph.D, Physics, Institute of Physics, Bhubaneswar , India
1989: M.Sc, Physics, Kurukshetra University, India
1986: B.Sc, Physics, Kurukshetra University, India

Academic Positions

2016 - : Professor H, Saha Institute of Nuclear Physics
2011 - 2016: Professor G, Saha Institute of Nuclear Physics
2007 - 2011: Professor F, Saha Institute of Nuclear Physics
2005 - 2007: Associate Professor E, Saha Institute of Nuclear Physics
2000 - 2005: Reader D, Saha Institute of Nuclear Physics
2001 - 2004: Visiting Fellow, Cyclotron Institute, Texas A&M University, USA
1997 - 2000: Reaserch Associate, Saha Institute of Nuclear Physics
1996 - 1997: Visiting Scientist, Baba Atomic Research Center, Mumbai, India

Awards / Honours

BSc. Gold Medal
SINP Foundation Day Award 2014

Selected Publications

" Strong correlations of neutron star radii with the slopes of nuclear matter incompressibility and symmetry energy at saturation."
N. Alam, B. K. Agrawal, M. Fortin, H. Pais, C. Providencia, Ad. R. Raduta, and A. Sulaksono.
Phys. Rev. C 94, 052801(R) (2016).

" Constraining the symmetry energy content of nuclear matter from nuclear masses: a covariance analysis.
C. Mondal, B. K. Agrawal and J. N. De.
Phys Rev. C 92, 024302 (2015).

" Information content of the weak-charge form factor.
P.-G. Reinhard,J. Piekarewicz, W. Nazarewicz, B. K. Agrawal, N. Paar,and X. Roca-Maza.
Phys Rev. C 88, 034325 (2013).

"Electric dipole polarizability and the neutron skin.
Jorge Piekarewicz, B.K. Agrawal, Gianluca Colo, Witold Nazarewicz,
Nils Paar, P-G Reinhard, Xavier Roca-Maza, Dario Vretenar.
Physical Review C 85, 041302 (2012).

" Determining the density content of symmetry energy and neutron skin: an empirical approach.
B.K. Agrawal, JN De, SK Samaddar.
Physical Review letters 109 , 262501 (2012).

Teaching / Guidance

Two lectures for the Post M.Sc. 2015-2016
Three lectures in CNT lectures on Selected Topics in Nuclear Theory, 15th-25th February, 2016
Six lectures in SERC School on Modern Microscopic Approaches in Nuclear Physics University of Kashmir, Srinagar, 17th May-6th June, 2016.

Chiranjib Mondal , likely to submit Ph.D. Thesis by September 2017.
Naosad Alam, likely to submit Ph.D. Thesis by September 2017.

Areas of Research Nuclear Structure
Nuclar Astrophysics

Research highlights:

The infinite nuclear matter is characterized by the nuclear constants, like, incompressibility coefficient, symmetry energy coefficient and their density derivatives. The nuclear constants are fundamentally important in determining the bulk properties of finite nuclei and neutron stars and yet some of them are only poorly known. The only way one can access the information about these nuclear constants is through their correlations with various bulk properties of the finite nuclei and neutron stars. One does not know a priori the existence of these correlations. The main focus of the research works is to identify the presence of strong and model independent correlations of various nuclear constants with the nuclear and neutron star observables. The nuclear Density Functional Theory is used with several accurately calibrated non-relativistic and relativistic energy density functionals. To assess the degree of correlation between nuclear observables and to explore systematic and statistical uncertainties on theoretical predictions, the chi-square statistical covariance technique is employed.

Parity-violating electron scattering provides a model-independent determination of the nuclear weak-charge form factor that has wide spread implications across such diverse areas as fundamental symmetries, nuclear structure, heavy-ion collisions, and neutron-star structure. The impact of precise measurements of the weak-charge form factor of ^{48}Ca and ^{208}Pb on the neutron skin thickness is assessed. The neutron-skin thickness is an important observable as it is strongly correlated with the slope of the symmetry energy at the saturation density. The strong correlation is found between the weak-charge form factor and the neutron radius, which accurately determines the neutron skin of neutron-rich nuclei. The optimal range of the momentum transfer 'q' is determined that maximizes the information content of the measured weak-charge form factor. Accurate measurements of the weak-charge form factor of ^{48}Ca and ^{208}Pb is proposed to have a profound impact on many aspects of nuclear theory and hadronic measurements of neutron skins of exotic nuclei at radioactive-beam facilities.

The strong and model independent correlations of neutron star radii with the linear combination of the slopes of the nuclear matter incompressibility coefficient and symmetry energy coefficient are reported for the first time. Such correlations are found to be more or less independent of the neutron star mass over a wide range. This correlation is traced back to be linked to the empirical relation existing between the star radius and the pressure at a nucleonic density between one and two times saturation density, and the dependence of the pressure on the nuclear matter incompressibility and the slope of symmetry energy. An universal correlation among various symmetry energy coefficients are also found.

Future Research Plan:

A unified nuclear energy density functional based on finite-range effective force is being developed. The derivation of such a density functional and their implementation to obtain numerical results for some test cases would result in a couple of publications by the end of next three years. Following this, the numerical calculations will be extended to realistic cases of astrophysical interest which would be important in view of the FRENA project at SINP.

Kumar Sankar Gupta, Senior Professor H+

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Education

1992: Ph.D. Syracuse University, Syracuse, USA.
1988: M.S. Syracuse University, Syracuse, USA.
1985: B.Sc. Presidency College, Calcutta, India.

Academic Positions

2016 - : Senior Professor H+, Saha Institute of Nuclear Physics.
2013 - 2016: Senior Professor H, Saha Institute of Nuclear Physics.
2007 - 2012: Professor G, Saha Institute of Nuclear Physics.
2004 - 2007: Professor F, Saha Institute of Nuclear Physics.
2000 - 2004: Associate Professor, Saha Institute of Nuclear Physics.
1996 - 2000: Reader, Saha Institute of Nuclear Physics.
1995 - 1996: Faculty Fellow, S.N.Bose National Centre.
1994 - 1995: Visiting Assistant Professor, Iowa State University.
1992 - 1994: Postdoctoral Fellow, University of Rochester.

Awards / Honours

Elected to the Editorial Board, European Physical Journal Plus, 2012.
Foundation Day Award, Saha Institute of Nuclear Physics, 2012.
Regular Associateship, Abdus Salam ICTP, Trieste, Italy, 2003 - 2010.
PI of Indo-Croatian (DST) & Indo-French (CEFIPRA) Project.
Graduate Fellowship, Syracuse University, USA, 1991-1992.
Graduate Assistantship, Syracuse University, USA, 1986-1991.
National Scholarship, Govt. of West Bengal, 1980, 1982.

Selected Publications

"Many-Body Physics, Topology and Geometry"
Siddhartha Sen and Kumar S. Gupta
World Scientific

"Noncommutative duality and fermionic quasinormal modes of the BTZ black hole"
Kumar S. Gupta, Tajron Juric, Andjelo Samsarov
JHEP 2017(6),1-26, DOI 10.1007/JHEP06(2017)107.

"Noncommutative scalar quasinormal modes and quantization of entropy of a BTZ black hole"
Kumar S. Gupta, E. Harikumar, Tajron Juric, Stjepan Meljanac, Andjelo Samsarov
JHEP **1509** *(2015) 025.*

"Mesoscopic structure formation in condensed matter due to vacuum fluctuations"
Siddhartha Sen, Kumar S. Gupta and J. M. D. Coey
J*Phys. Rev.* **B 92**, *155115 (2015).*

"Coulomb screening in graphene with topological defects."
Baishali Chakraborty, Kumar S. Gupta and Siddhartha Sen
Eur. Phys. Jour. **B 88**, *(2015) 155.*

"Entropy from Scaling Symmetry Breaking"
Neymar Cavalcante, Saulo Diles, Kumar S. Gupta and Amilcar R. de Queiroz
EPL **110**, *(2015) 48002.*

"Effects of Noncommutativity on the Black Hole Entropy"
Kumar S. Gupta, E. Harikumar, Tajron Juric, Stjepan Meljanac and Andjelo Samsarov
Adv. High Energy Phys. **2014** *139172 (2014).*

"Anomalies and Renormalization of Impure States in Quantum Theories"
Kumar S. Gupta and Amilcar Queiroz

Mod. Phys. Lett. **A 29** *(2014) 13, 1450064*.

"Different Realizations of the κ-Momentum Space and Relative-locality Effect."
S. Meljanac, A. Pachol, A. Samsarov and Kumar S. Gupta,.
Phys. Rev. **D 87**, *125009 (2013)*.

"Effect of Topological Defects and Coulomb Charge on the Low Energy Quantum Dynamics of Gapped Graphene."
Baishali Chakraborty, Kumar S. Gupta and Siddhartha Sen
J*J. Phys. A: Math. Theor.* **46** *(2013) 055303*.

"A Dirac Type xp-Model and the Riemann Zeros."
Kumar S. Gupta, E. Harikumar and Amilcar R. de Queiroz,.
Europys. Lett. **102** *(2013) 10006*.

"Phase Structure of Fuzzy Black Holes."
S. Digal, T.R. Govindarajan, Kumar S. Gupta and X. Martin
JHEP **1201**, *027 (2012)*.

"Quantum statistics and noncommutative black holes."
Kumar S. Gupta, S. Meljanac and A. Samsarov.
Phys.Rev. **D 85**, *045029 (2012)*.

Teaching / Guidance
Supervised the Ph.D. thesis of Smt. Baishali Chakraborty, degree awarded in February 2016.
Taught P.MSc. courses Advanced Topics in Theoretical Physics (2013) and Quantum Mechanics (2016).
Presently supervising Shri Supriyo Ghosh on his P.MSc. review.

Areas of Research
Noncommutativity and Planck scale effects on black holes and gravitational waves.
Non-equilibrium aspects of quantum dynamics and entanglement in quantum systems.
Topological and field theoretic effects in lower dimensional and mesoscopic systems.

Essential Strength of Research:

In the last few years I have worked on three primary areas, including **effect of Planck scale physics on black holes and gravitational waves**, **topological and field theoretic effects on graphene and mesoscopic** and **anomaly, renormalization and entropy in scale invariant quantum systems**. It is well known that general relativity and quantum uncertainty principle leads to noncommutative structure of space-time at the Planck scale. Using this framework, we have calculated the Planck sale correction to the Bekenstein-Hawking entropy. In addition, we have also calculated the Planck scale corrections to various quasi-normal modes of black holes, which capture many essential features of the gravitational waves. We have studied both gapless and gapped graphene in the presence of a Coulomb charge and a topological defect. We have shown that the critical charge depends on the sample topology. This leads to a definite experimental prediction of a topological effect. We have also studied the effect of topological defects on charge screening in graphene. In addition, we have shown that quantum vacuum fluctuations can lead to coherent structures in mesoscopic systems and our prediction has already been experimentally verified. Finally, we have investigated anomalies and entropy in sale invariant systems. Our ideas have led to an analysis of Riemann zeros in certain fermionic systems.

Future Research Plan:

In the next few years I would like to study the **quantum gravity effects on scale invariant systems** with the idea of investigating how such effects can lead to scaling anomalies and associated phenomena. In particular, the issues of how holography and CFT are affected by the physics at the Planck scale would be investigated. Such effects are expected to show up both in black hole physics as well as in boundary conformal field theories, which are of great current interest. I would also like to study the **time dependence of the entanglement entropy in quantum systems**, with a view to connect the theoretical analysis with recent experiments. We want to undertake a full scale non-equilibrium time dependent study of entanglement in field theories and many-body systems. The related ideas such as survival probability, Loschmidt echo and orthogonality catastrophe would also be investigated. It would be useful to develop a good synergy between theorists and experimentalists in this context.

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Education

1993: Ph.D. Physics, Indian Institute of Technology, Kanpur, India
1986: M.Sc. Physics, Cochin University of Science and Technology, Cochin, India
1983: B.Sc. Physics, University of Kerala, Kerala, India

Academic Positions

2011 - : Professor G, Saha Institute of Nuclear Physics
2007 - 2011: Professor F, Saha Institute of Nuclear Physics
2004 - 2007: Associate Professor E, Saha Institute of Nuclear Physics
2001 - 2004: Lecturer, University of Hyderabad

1999 - 2001: Postdoctoral Fellow, Instituto de Fisica Teorica, São Paulo, Brazil
1996 - 1999: Postdoctoral Fellow, Tata Institute of Fundamental Research, Bombay, India
1993 - 1996: Postdoctoral Fellow, Centre for Theoretical Studies, Indian Institute of Science, Bangalore, India

Awards / Honours

Regular Associate, The Abdus Salam ICTP, Trieste, Italy (2002 - 2009)
Commonwealth Fellow, Institute of Particle Physics Phenomenology, Univ. of Durham, UK (2004 - 2005)

Selected Publications

NNLO QCD Corrections to the Drell-Yan Cross Section in Models of TeV-Scale Gravity,
T. Ahmed, P. Banerjee, P.K. Dhani, M.C. Kumar, P. Mathews, N. Rana, V. Ravindran,
Eur.Phys.J. C77 (2017) 22

Pseudo-scalar Higgs Boson Production at Threshold N3LO and N3LL QCD
T. Ahmed, M.C. Kumar, P. Mathews, N. Rana, V. Ravindran,
Eur. Phys. J. C76 (2016) 355

Pseudo-scalar Form Factors at Three Loops in QCD
T. Ahmed, T. Gehrmann, P. Mathews, N. Rana, V. Ravindran,
JHEP 1511 (2015) 169

Neutral Triple Vector Boson Production in Randall-Sundrum Model at the LHC,
G. Das, P. Mathews,
Phys.Rev. D92 (2015) 094034

RS resonance in di-final state production at the LHC to NLO+PS accuracy,
G. Das, P. Mathews, V. Ravindran, S. Seth,
JHEP 1410 (2014) 188

Two-Loop QCD Correction to Higgs $\rightarrow b + \bar{b} + g$ Amplitude,
T. Ahmed, M. Mahakhud, P. Mathews, N. Rana, V. Ravindran,
JHEP 1408 (2014) 075

Three photon production to NLO+PS accuracy at the LHC ,
M.K. Mandal, P. Mathews, V. Ravindran, S. Seth,
Eur. Phys. J. C74 (2014) 3044

Next-to-Next-to-Leading Order QCD Corrections in Models of TeV-Scale Gravity,
D. de Florian, M. Mahakhud, P. Mathews, J. Mazzitelli, V. Ravindran,
JHEP 1404 (2014) 028

Drell-Yan, ZZ, W^+W^- production in SM & ADD model to NLO+PS accuracy at the LHC,
R. Frederix, M.K. Mandal, P. Mathews, V. Ravindran, S. Seth,
Eur. Phys. J. C74 (2014) 2745

A framework for Higgs characterisation,
P. Artoisenet, P. de Aquino, F. Demartin, R. Frederix, S. Frixione, F. Maltoni, M. K. Mandal, P Mathews, K. Mawatari, V. Ravindran, S. Seth, P. Torrielli, M. Zaro,
JHEP 1311 (2013) 043,
Cited 113 times (INSPIRES)

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

Teaching / Guidance

In June 2017, Mr. G. Das, defended his PhD Thesis submitted to HBNI

Lecturers on Quantum Chromodynamics at the School-cum-workshop on Collider Physics: Events, Analysis and QCD, Indian Institute of Technology, Guwahati, March 2017

Lecturers on Deep Inelastic Scattering at the DST - SERC School on Nuclear Matter under Extreme Conditions, VECC, Kolkata, Jan. 2013

Taught in SINP graduate courses

Areas of Research

High Energy Physics Phenomenology, with special emphasis on Physics beyond the SM and perturbative Quantum Chromodynamics.

Essential Strength of Research:

Main research focus in the past few years have been on precision physics at the LHC. To fully benefit from the experimental program at the LHC, precise theoretical predictions for both signals of new physics and SM background are very essential. This requires in-depth understanding of perturbative structure of multi-loop and multi-leg QCD amplitudes. State-of-the-art quantum field theoretical techniques are used to compute higher order QCD corrections to observables at the LHC. Some of the important recent contributions are: (a) performed the very first calculation involving a massive spin-2 particle at NNLO level in QCD for the production of a pair of leptons at hadron colliders, wherein the massive spin two could couple to the SM *via* a universal energy-momentum tensor or via a non-universal couplings. The corrections are not only large but also important to stabilise the predictions with respect to the unphysical renormalisation and factorisation scales. (b) computed the three-loop massless QCD corrections to the quark and gluon form factors of pseudo-scalar operators. The three-loop corrections to the pseudo-scalar form factors are an important ingredient to precision Higgs phenomenology. (c) Higgs Characterisation: Effective field theory approach is one the powerful methods to study the characterisation of the Higgs boson discovered at the LHC. Given that there are large number of higher dimensional operators, a systematic approach in a automated framework is essential. Using MadGraph 5 and aMC@NLO, we have incorporated relevant higher dimensional operators along with next to leading order QCD effects to study spin and parity properties of the Higgs boson.

Future Research Plan:

With the absence of any signal of new physics at the LHC, searches of physics beyond the Standard Model (BSM) is based on the ability to make very precise theoretical predictions within the SM and to look for possible deviations between experimental observations and theoretical predictions, this program may yield direct or indirect evidence of physics beyond the Standard Model within estimated uncertainties. The Higgs boson discovery could be viewed as the foundation for a long-term precision physics program measuring the properties of the Higgs boson, its coupling to itself and to other elementary particles. The inclusion in the predictions of higher order quantum effects at fixed order in perturbative expansion and the resummation to all orders will improve the accuracy of important measured observables. Consequently these predictions will help constrain variety of BSM scenarios.

Bireswar Basu-Mallick, Senior Professor H

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Education

1993: Ph.D, Physics, Saha Institute of Nuclear Physics, Kolkata, India
1985: M.Sc, Physics, University of Calcutta, Kolkata, India
1982: B.Sc, Physics, University of Calcutta (Presidency College), Kolkata, India

Academic Positions

2010-2016: Professor G, Saha Institute of Nuclear Physics, Kolkata, India
2007-2010: Professor F, Saha Institute of Nuclear Physics, Kolkata, India
2003-2007: Associate Professor E, Saha Institute of Nuclear Physics, Kolkata, India
2000-2003: Reader D, Saha Institute of Nuclear Physics, Kolkata, India
1999-2000: Visiting Scientist, Saha Institute of Nuclear Physics, Kolkata, India
1997 - 1999: JSPS Post-doctoral Fellow, University of Tokyo, Tokyo, Japan
1995 - 1997: Visiting Fellow, Tata Institute of Fundamental Research,Mumbai, India
1993 - 1995: Post-doctoral Fellow, Institute of Mathematical Sciences, Chennai, India

Awards / Honours and distinctions

Senior Associateship award, Abdus Salam ICTP, Trieste, Italy (2008-2015)
Appointed as 'Honorary Collaborator' by the Faculty of Physics, Universidad Complutense, Madrid (2010-2011)
JSPS Post-doctoral Fellowship from Japanese Society for the Promotion of Science (1997-1999)
Given Plenary talks in International Conferences on quantum integrable systems in 2010 and 2014

Selected Publications

" Super Rogers-Szegö polynomials associated with BC_N type of Polychronakos spin chains",
B. Basu-Mallick and C. Datta,
Nucl. Phys. B 921 (2017) 59.

" Quasi exactly solvable extension of Calogero model associated with exceptional orthogonal polynomials" ,
B. Basu-Mallick, Bhabani Prasad Mandal and Pinaki Roy,
Annals of Phys. 380 (2017) 206.

"Integrable open spin chains related to infinite matrix product states",
B. Basu-Mallick, F. Finkel and A. González-López,
Phys. Rev. B 93 (2016) 155154.

" Supersymmetric analogue of BC_N type rational integrable models with polarized spin reversal operators",
P. Banerjee, B. Basu-Mallick, N. Bondyopadhaya and C. Datta,
Nucl. Phys. B 904 (2016) 297.

"Partition functions of Polychronakos like spin chains associated with polarized spin reversal operators",
B. Basu-Mallick, Nilanjan Bondyopadhaya and Pratyay Banerjee,
Nucl. Phys. B 883 (2014) 501.

"Clusters of bound particles in the derivative delta-function Bose gas",
B. Basu-Mallick, Tanaya Bhattacharyya and Diptiman Sen,
Nucl. Phys. B 871 (2013) 362.

"The exactly solvable spin Sutherland model of B_N type and its related spin chain",
B. Basu-Mallick, F. Finkel and A. González-López,
Nucl. Phys. B 866 (2013) 391.

"Level density distribution for one-dimensional vertex models related to Haldane-Shastry like spin chains", Pratyay Banerjee and B. Basu-Mallick,
J. Math. Phys. 53 (2012) 083301.

Teaching / Guidance Supervised the Ph.D. thesis of one student, who has obtained Ph.D. degree from University of Calcutta on March, 2015. At present supervising the Ph.D thesis of another student, who is expected to submit the thesis by August, 2017.
Taught a subject with title 'Group theory and Lie algebra' for SINP Post M.Sc. Associate Course. Taught a short course (3 talks) with title 'Exactly solvable many particle systems' in the Workshop 'Recent developments in quantum theories', at Banaras Hindu University, Varanasi, during February, 2015.

Areas of Research Quantum integrable and exactly solvable dynamical systems as well as spin chains; Yang-Baxter equation; Quantum groups; Application of Yangian symmetry, conformal field theory, random matrix theory, number theory etc. in quantum integrable systems.

Highlights of Research and Developmental work:

- A non-periodic version of the Haldane-Shastry spin chain, whose ground state can be obtained from the chiral correlator of the $c = m - 1$ free boson boundary conformal field theory, has been studied. It has been shown that this model is integrable for a suitable choice of the chain sites depending on the roots of the Jacobi polynomial $P_N^{\beta-1,\beta'-1}$, where N is the number of sites and β, β' are two positive parameters. A complete description for the spectrum of this spin chain has been given in terms of Haldane's motifs and a related classical vertex model.
- Polarized spin reversal operators along with their supersymmetric analogues have been used to construct new exactly solvable BC_N type of quantum integrable spin Calogero models and Polychronakos spin chains. Partition functions of these spin chains have been computed by using the freezing trick and it has been shown that such partition functions obey an 'extended' boson-fermion duality relation.
- Novel multivariate super Rogers-Szegö polynomials, depending on four different types of variables, have been proposed and the corresponding generating functions have been constructed. A set of recursion relations for the partition functions of the BC_N type of Polychronakos spin chains, involving different numbers of lattice sites and internal degrees of freedom, have been derived by using such generating functions of super Rogers-Szegö polynomials.
- The spectrum of the su(m) spin Sutherland model of B_N type has been computed and the partition function of the related spin chain of Haldane-Shastry type has been evaluated in closed form by using the freezing trick.
- It has been shown analytically that the level density distribution for a class of one-dimensional vertex models with polynomial type energy functions follow the Gaussian pattern for large number of vertices.
- It has been shown that clusters of bound particles can be constructed for a quantum integrable derivative δ-function Bose gas for some special values of the coupling constant. A connection between those special values of the coupling constant and some fractions belonging to the Farey sequences in number theory has also been established. This connection has led to a classification of the clusters of bound particles associated with the derivative δ-function Bose gas and allowed us to study various properties of these clusters like their size and their stability under the variation of the coupling constant.

Future Research Plan:

Various properties of quantum integrable spin systems with long-range interaction and their supersymmetric generalizations, like the corresponding spectra, thermodynamical properties, correlation functions and entanglement entropy, will be studied. Related topics like Yangian quantum group symmetry, recursion relations for multivariable Rogers-Szegö type polynomials, Haldane's motifs, random matrix theory, classical vertex models and infinite matrix product states in conformal field theory will also be explored in connection with quantum integrable spin models with long-range interaction. Furthermore, various statistical properties associated with the spectra of such quantum integrable spin models, e.g., level density distribution and nearest neighbour spacing distribution, will be investigated by using analytical techniques and symbolic software package like Mathematica.

Munshi G Mustafa, Senior Professor H^+

Personal Details:

DoB: 22nd February, 1962

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Education:

1995: Ph.D, Physics, Institute of Physics (Utkal Univ.), Bhubaneswar, India

1989: Pre-Doctoral, Institute of Physics, Bhubaneswar, India

1987: M.Sc, Physics, Visva-Bharati University, Santineketan, West Bengal, India

1984: B.Sc, Physics, Burdwan University, Burdwan, India

Academic Positions:

July 2016 - : Professor H^+, Saha Institute of Nuclear Physics

2013 - 2016: Professor H, Saha Institute of Nuclear Physics

1997 - 2001: Reader, Saha Institute of Nuclear Physics

2002 - 2003: Alexander von Humboldt Fellow, University of Giessen, Giessen, Germany

1999 - 2000: Alexander von Humboldt Fellow, University of Giessen, Giessen, Germany

1995 - 1997: Postdoctoral Fellow, Variable Energy Cyclotron Centre, Kolkata, India

Awards / Honours:

Awarded "BANGABHUSHAN" in 2014 by Government of West Bengal, India, for outstanding performance in Basic Sciences.

Awarded SINP Foundation Day Medal in 2009 and 2011

Chancellor's nominee to the academic council in Kalyani University, WB.

Memeber of "International Advisory Committee" of the 7th International Conference in Physics and Astrophysics of Quark Gluon Plasma (ICPAQGP) , February 1-6, 2015, Kolkata, India.

Awarded "FZD Fellow", Forschungzentrum Dresden-Rossendorf, Germany [July 1-Sept. 30, 2008] .

Awarded "Visitorship" under the project McGill India Strategic Research Initiative (MISRI), Department of Physics, McGill University, Montreal, [June 20 - September 14, 2007].

Awarded "Alexander von Humboldt Fellowship" by the AvH foundation, Bonn, Germany [April 1, 2002 to March 31, 2003].

Awarded "Alexander von Humboldt Fellowship" by the AvH foundation, Bonn, Germany [January 1, 1999 to March 31, 2000].

Selected Publications (since 2012):

1. *"Power corrections to the electromagnetic spectral function and the dilepton rate in QCD plasma within operator product expansion in $D = 4$"*, Aritra Bandyopadhyay and **Munshi G. Mustafa** , *JHEP 1611 (2016) 183*
2. *"Electromagnetic spectral properties and Debye screening of a strongly magnetized hot medium"*, Aritra Bandyopadhyay, Chowdhury Aminul Islam and **Munshi G. Mustafa** , *Phys. Rev. D94 (2016) 114034*
3. *"Dilepton rate and quark number susceptibility with the Gribov action"*, Aritra Bandyopadhyay, Najmul Haque, **Munshi G. Mustafa** and Michael Strickland, *Phys. Rev. D93 (2016) 065004*
4. *"Three-loop hard-thermal-loop perturbation theory thermodynamics at finite temperature and finite baryonic and isospin chemical potential",* Jens O. Andersen, Najmul Haque, **Munshi G. Mustafa** and Michael Strickland, *Phys. Rev. D93 (2016) 054045*
5. *"Vector meson spectral function and dilepton production rate in a hot and dense medium within an effective QCD approach"*, Chowdhury Aminul Islam, Sarbani Majumder, Najmul Haque and **Munshi G. Mustafa** , *JHEP 1502 (2015) 011*
6. *"Three-loop HTLpt thermodynamics at finite temperature and chemical potential"*, Najmul Haque, Aritra Bandyopadhyay, Jens O. Andersen, **Munshi G. Mustafa** , Michael Strickland and Nan Su, *JHEP 1405 (2014) 027*

7. “*Quark Number Susceptibility : Revisited with Fluctuation-Dissipation Theorem in mean field theories”*, Sanjay K. Ghosh, Anirban Lahiri, Sarbani Majumder, **Munshi G. Mustafa** , Sibaji Raha and Rajarshi Ray, *Phys. Rev. D90 (2014) 054030*
8. *Three-loop pressure and susceptibility at finite temperature and density from hard-thermal-loop perturbation theory*, Najmul Haque, Jens O. Andersen, **Munshi G. Mustafa** , Michael Strickland and Nan Su, *Phys. Rev. D89 (2014) 061701*
9. “*Quark Number Susceptibilities from Two-Loop Hard Thermal Loop Perturbation Theory”*, Najmul Haque, **Munshi G. Mustafa** and Michael Strickland, *JHEP 1307 (2013) 184*
10. “*Heavy quark energy loss and D-Mesons at RHIC and LHC energies”*, Raktim Abir, Umme Jamil, **Munshi G. Mustafa** and Dinesh K. Srivastava, *Phys. Lett. B715 (2012) 183*

Teaching / Guidance:

Teach regularly in Post MSc course in SINP; Integrated MSc course in Bose Institute

A pedagogical talk in Students’ Day on “QCD and its Application to the Hot and Dense matter created in Heavy-ion Collisions” at “6th Asian Triangular Heavy-Ion Collisions (ATHIC)”, India International Centre, New Delhi, February 15-19, 2016

Taught “Finite Temperature Field Theory” at SERC Advanced School on Theoretical High Energy Physics, November-December, 2015

Rapature -II (Summary Talk for Theory), 7th International Conference on Physics and Astrophysics of Quark Gluon Plasma (ICPAQGP), Kolkata, Feb 1-6, 2015

A set of seven lectures on “Quantum Field Theory at Finite Temperature and density at FAIR Physics on Compressed Baryonic Matter, January 20-24, 2014, Bose Institute, Darjeeling, India

Dr. Purnendu Chakraborty: PhD awarded in 2007; PDF at Univ. of Minnesota, USA , Nov 2007-Aug 2010; PDF at PRL Ahemdabad, Jan. 2011-Dec. 2012; PDF at VECC March 2012-Feb. 2014; joined Basirhat Govt. College, WB since May 2014

Dr. Raktim Abir: PhD awarded in January 2014; PDF at Wayne State Univ., USA, Nov 2013- August 2015; Assistant Professor at Aligarh Muslim Univ. since September 2015

Dr. Najmul Haque: PhD awarded in February 2015, PDF at Kent State Univ., USA, April 2015-April 2016; Alexander von Humboldt Fellow, University of Giessen, Germany, since June 2016

Dr. Chowdhury Aminul Islam, PhD awarded in February 2017, PDF at VECC, Kolkata since January 2017; would join TIFR, Mumbai as a PDF in November 2017

Aritra Bandyopadhyay: submitted thesis in July, 2017, already has a PDF offer from Brazil

Aritra Das: currently working for his PhD degree (Co-guide)

Bithika Karmakar: presently pursuing a project work as a part of SINP PMSc course and would join in August 2017 for PhD work

Areas of Research:

High energy Nuclear Physics; Phenomenology of Quark-Gluon Plasma (QGP); Perturbative and noperturbative QCD at finite temperature and density and their application to QGP

Essential Strength of Research:

The hot and dense matter (QGP) produced in high energy heavy-ion collisions is a many-body system that seeks theoretical tools from an interface of particle physics and high energy nuclear physics. This requires the systematic use of QCD methods (both perturbative and nonperturbative) with a strong overlap from (i) Finite temperature and density field theory, (ii) Relativistic fluid dynamics, (iii) Kinetic or transport theory, (iv) Quantum collision theory, (v) Statistical mechanics and thermodynamics. Actively involved in addressing the various aspects of QGP by using phenomenology, perturbative and nonperturbative methods of QCD.

Future Research Plan:

Intend to work on the relevant observables which are very sensitive to high density effects and phase transition at FAIR energies. We also plan to develop a theoretical framework to make quantitative estimates of static and dynamic quantities (i) in small systems (pA collisions) with Dirichlet boundary condition (ii) hot and dense magnetized QCD matter and its evolution using magnetohydrodynamics.

Shibaji Roy, Senior Professor H+

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Education

1991: Ph.D, Physics, University of Rochester, Rochester, NY, USA
1983: M.Sc, Physics, Calcutta University, Kolkata, India
1981: B.Sc, Physics, Presidency College, Kolkata, India

Academic Positions

2016 - : Senior Professor H+, Saha Institute of Nuclear Physics, Kolkata, India
2012 - 2016: Senior Professor H, Saha Institute of Nuclear Physics, Kolkata, India
2007 - 2012: Professor G, Saha Institute of Nuclear Physics, Kolkata, India
2004 - 2007: Professor F, Saha Institute of Nuclear Physics, Kolkata, India
2000 - 2004: Associate Professor E, Saha Institute of Nuclear Physics, Kolkata, India
1997 - 2000: Reader D, Saha Institute of Nuclear Physics, Kolkata, India
1995 - 1997: Postdoctoral Research Fellow, University of Santiago de Compostela, Spain
1993 - 1995: Postdoctoral Research Fellow, University of Groningen, The Netherlands
1991 - 1993: Postdoctoral Research Fellow, International Centre for Theoretical Physics, Trieste, Italy

Awards / Honours

None

Selected Publications

1. *"Decoupling limit and throat geometry of non-susy D3 brane,"* K. Nayek and S. Roy, *Phys. Lett. B* **766**, *192 (2017)*, *arXiv:1608.05036 [hep-th].*
2. *"Non-susy D3 brane and an interpolating solution between AdS_5 black hole, AdS_5 soliton and a soft-wall gravity solution,"* S. Roy, *JHEP* **1510**, *113 (2015)*, *arXiv:1508.06730 [hep-th].*
3. *"Decoupling of gravity on non-susy Dp branes,"* K. Nayek and S. Roy, *JHEP* **1603**, *102 (2016)*, *arXiv:1506.08583 [hep-th].*
4. *"Entanglement thermodynamics for an excited state of Lifshitz system,"* S. Chakraborty, P. Dey, S. Karar and S. Roy, *JHEP* **1504**, *133 (2015)*, *arXiv:1412.1276 [hep-th].*
5. *"Space-like Dp branes: accelerating cosmologies versus conformally de Sitter space-time,"* K. Nayek and S. Roy, *JHEP* **1502**, *021 (2015)*, *arXiv:1411.2444 [hep-th].*
6. *"Interpolating solution from AdS_5 to hyperscaling violating Lifshitz space-time,"* P. Dey and S. Roy, *Phys. Rev. D* **91**, *no. 2, 026005 (2015)*, *arXiv:1406.5992 [hep-th].*
7. *"Conformally de Sitter space from anisotropic space-like D3-brane of type IIB string theory,"* S. Roy, *Phys. Rev. D* **89**, *no. 10, 104044 (2014)*, *arXiv:1402.2912 [hep-th].*
8. *"Modification of phase structure of black D6 branes in a canonical ensemble and its origin,"* J. X. Lu, J. Ouyang and S. Roy, *Phys. Rev. D* **90**, *no. 6, 066003 (2014)*, *arXiv:1401.4343 [hep-th].*
9. *"Zero sound in strange metals with hyperscaling violation from holography,"* P. Dey and S. Roy, *Phys. Rev. D* **88**, *046010 (2013)*, *arXiv:1307.0195 [hep-th].*
10. *"From AdS to Schrödinger/Lifshitz dual space-times without or with hyperscaling violation,"* P. Dey and S. Roy, *JHEP* **1311**, *113 (2013)*, *arXiv:1306.1071 [hep-th].*
11. *"Lifshitz metric with hyperscaling violation from NS5-Dp states in string theory,"* P. Dey and S. Roy, *Phys. Lett. B* **720**, *419 (2013)*, *arXiv:1209.1049 [hep-th].*
12. *"Holographic entanglement entropy of the near horizon 1/4 BPS F-Dp bound states,"* P. Dey and S. Roy, *Phys. Rev. D* **87**, *no. 6, 066001 (2013)*, *arXiv:1208.1820 [hep-th].*
13. *"Intersecting D-branes and Lifshitz-like space-time,"* P. Dey and S. Roy, *Phys. Rev. D* **86**, *066009 (2012)*, *arXiv:1204.4858 [hep-th].*

14. *"Lifshitz-like space-time from intersecting branes in string/M theory,"* P. Dey and S. Roy, *JHEP* **1206**, *129 (2012)*, *arXiv:1203.5381 [hep-th].*
15. *"Wilson loops in noncommutative Yang-Mills theory using gauge/gravity duality,"* S. Chakraborty, N. Haque and S. Roy, *Nucl. Phys. B* **862**, *650 (2012)*, *arXiv:1201.0129 [hep-th].*
16. *"The enriched phase structure of black branes in canonical ensemble,"* J. X. Lu, S. Roy and Z. Xiao, *Nucl. Phys. B* **854**, *913 (2012)*, *arXiv:1105.6323 [hep-th].*
17. *"Calculating the jet quenching parameter in the plasma of NCYM theory from gauge/gravity duality,"* S. Chakraborty and S. Roy, *Phys. Rev. D* **85**, *046006 (2012)*, *arXiv:1105.3384 [hep-th].*

Teaching / Guidance

Taught Quantum Field Theory I to post-MSc students during December-March, 2014-2015.

1. Somdeb Chakraborty (completed PhD in June, 2015, currently Faculty in Maulana Azad College, Kolkata)
2. Parijat Dey (completed PhD in August, 2015, currently a post-doc in CHEP, IISc., Bangalore)
3. Kuntal Nayek has finished his PhD work and will submit thesis in September/October, 2017

Areas of Research

M/String theory, AdS/CFT, AdS/CMT, S-branes and non-susy branes, Gauge/gravity duality and applications

Essential Strength of Research:

In the absence of any rigorous method to handle strongly coupled field theory, AdS/CFT correspondence or generally the gauge/gravity duality is a very useful tool in such situation. AdS/CFT uses holography to relate strongly coupled field theories to weakly coupled string theory or supergravity and makes calculation simple. It can be applied to (a) quark-gluon plasma (QGP), (b) many body systems (AdS/CMT) and (c) also to non-supersymmetric (non-susy) systems. These are some of the topics explored in the works mentioned above. Using AdS/CFT some properties, like, screening length, quark-antiquark potential, radiative energy loss of quarkonium or jet quenching parameter of the QGP in non-commutative space have been studied and compared with the commutative results. Through constructions of certain bound states of string theory and taking near horizon limit certain scaling solutions relevant for many body systems at quantum criticality have been obtained. Their entanglement entropies have been obtained holographically through which various phases of matter can be identified. Certain gravity dual of 'strange metal' with hyperscaling violation has been shown to exhibit zero sound behavior analogous to 'strange metal' without hyperscaling violation. It has been shown that excited states of scaling solutions satisfy certain first law analogous to the first law of thermodynamics known as first law of entanglement thermodynamics. For non-susy solutions it has been shown that bulk gravity decouples from the brane analogous to BPS solutions and thus giving rise to an interesting possibility of extending AdS/CFT in the non-susy cases. The explicit decoupling is obtained for non-susy D3 branes. Moreover, certain time-dependent solutions and their cosmological implications are also explored. Phase structures of certain black brane systems have also been studied.

Future Research Plan:

As mentioned before, the decoupling of bulk gravity from non-susy branes suggests that it might be possible to obtain AdS/CFT type correspondence even for the non-supersymmetric cases. Indeed for non-susy D3 brane the explicit decoupling limit and the corresponding throat geometry has been obtained when the charge of the non-susy D3 brane is very large i.e., near the extremality. This geometry can be thought of as the holographic dual to a non-susy gauge theory on the boundary. So, using this geometry one can study the properties of QGP corresponding to non-susy Yang-Mills theory. Presently this problem is being studied and some preliminary results have been obtained. It would also be interesting to work out the detail decoupling limit of other Dp branes when $p \neq 3$. This is one of the future programs. After obtaining the decoupled geometry the properties of QGP in other dimensions can be studied. These geometries are either asymptotically AdS or conformal to AdS. So, one can think of them as some excited states of AdS geometry. Therefore it would be interesting to compute the entanglement entropy, complexity of these systems and also their connections to fidelity susceptibility relevant in the quantum information theory. BPS branes of string theory are known to be stable under small perturbation of the metric. However, the black branes are not stable and suffers from Gregory-Laflamme instability under small metric perturbation. However, the instability goes away as we go near the extremality. Similarly it would be interesting to see what happens for the non-susy branes. So, another future program includes the study of gravitational stability of the non-susy branes. However, since in the decoupling limit the solution goes near the extremality, the stability should be restored like near-extremal black branes.

Asit K De, Senior Professor H

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Education

1988: Ph.D. Physics, The Ohio State University, Columbus, Ohio, USA
1983: M.S. Physics, Carnegie-Mellon University, Pittsburgh, Pennsylvania, USA
1981: M.Sc. Physics, University of Calcutta, Kolkata, India
1979: B.Sc. Physics, Presidency College, University of Calcutta, Kolkata, India

Academic Positions

1994 - now: Faculty member (currently Senior Professor), Theory Division, Saha Institute of Nuclear Physics
1992 - 1994: Postdoctoral Fellow, Department of Physics, Washington University, St.Louis, Missouri, USA
1988 - 1992: Guest Scientist, HLRZ, KFA / Forschungszentrum, Juelich, Germany
1988 - 1992: Postdoctoral Fellow, Institute for Theoretical Physics, RWTH, Aachen, Germany

Academic Distinctions

Invitations for plenary talks at International conferences, e.g., LIGHT CONE 2017.

My papers cited in 2 text books in Lattice Field Theory authored by Montvay & Muenster, and by Jan Smit (both published from Cambridge University Press).

Invited review article “Chiral Gauge Theories on Lattice” in Frontiers in High Energy Physics, the 75 year commemorative volume of the Indian Journal of Physics, eds. A. Raychaudhuri & P. Mitra, Allied Publishers (2004).

Invited review article “Yukawa models on the lattice” (with J. Jersak) as a chapter in the book “Heavy Flavors”, eds. Buras & Lindner, World Scientific (1992).

My work [Nucl. Phys. B 388 (1992) 243] in collaboration with W. Bock & J. Smit chosen for topical plenary talk at LATTICE 1991, KEK, Japan.

Invited plenary talk at the Chiral Gauge Theory Workshop in Rome, Italy (1992), attended by G. Parisi, L. Maiani, H. Georgi, C. Becchi, M. Tonin, T. Banks, H. Nielsen, L. Randall, J. Smit (co-founder of Lattice Gauge Theory), some of whom took active interest in organising the workshop.

Second place award among all presentations of Science PhD students, The Ohio State University, USA (1987).

Recent Selected Publications

Tricritical points in a compact $U(1)$ lattice gauge theory at strong coupling,
A. K. De and M. Sarkar,
***Phys. Rev. D* 93 *(2016) no.11, 114504*.**

Pion and nucleon in two flavour QCD with unimproved Wilson fermions,
A. Chowdhury, A. K. De, S. De Sarkar, A. Harindranath, J. Maiti, S. Mondal and A. Sarkar,
***Nucl. Phys. B* 871 *(2013) 82*.**

Exploring autocorrelations in two-flavour Wilson Lattice QCD using DD-HMC algorithm,
A. Chowdhury, A. K. De, S. De Sarkar, A. Harindranath, J. Maiti, S. Mondal and A. Sarkar,
***Comput. Phys. Commun.* 184 *(2013) 1439*.**

Topological charge density correlator in Lattice QCD with two flavours of unimproved Wilson fermions,
A. Chowdhury, A. K. De, A. Harindranath, J. Maiti and S. Mondal,
***JHEP* 1211 *(2012) 029*.**

Low lying hadron spectrum and chiral condensate with two flavours of naive Wilson fermions,
A. Chowdhury, A. K. De, S. De Sarkar, A. Harindranath, J. Maiti, S. Mondal and A. Sarkar,
***PoS LATTICE* 2012 *(2012) 208*.**

Topological susceptibility in Lattice QCD with unimproved Wilson fermions,
A. Chowdhury, A. K. De, S. De Sarkar, A. Harindranath, S. Mondal, A. Sarkar and J. Maiti,
***Phys. Lett. B* 707 *(2012) 228*.**

Effect of r averaging on Chiral Anomaly in Lattice QCD with Wilson Fermion: Finite volume and cutoff effects,
A. K. De, A. Harindranath and S. Mondal,
***JHEP* 1107 *(2011) 117*.**

Spanning of Topological sectors, charge and susceptibility with naive Wilson fermions ,
A. Chowdhury, A. K. De, S. De Sarkar, A. Harindranath, J. Maiti, S. Mondal, and A. Sarkar,
***PoS LATTICE* 2011 *(2011) 099*.**

Teaching / Guidance

Current student:
Mugdha Sarkar, registered with HBNI, PhD expected in 2018. Thesis topic: Non-perturbative gauge-fixing of compact lattice gauge fields.

Previous students:
Tilak Sinha (PhD 2006, Jadavpur University), post-doctoral fellowship at University of Wuppertal, Germany; currently a faculty member at Narasinha Dutt College (University of Calcutta).

Subhasish Basak (PhD 2003, University of Calcutta), post-doctoral fellowships at University of Maryland, College Park, MD, USA and Indiana University, Bloomington, IN, USA; currently a faculty member at NISER, Bhubaneswar.

SINP graduate level (Post-MSc) courses taught (since 2011)
7 full courses and one half course in Quantum Field Theory I, Quantum Field Theory II, Quantum Mechanics & Particle Physics (A full course constitutes approximately 40 to 50 lectures each of 90 minutes duration).

Areas of Research

General area: Non-perturbative study of Quantum Field Theories regularised on lattice.

Specific areas: (i) Lattice fermions and chiral symmetry, (ii) Lattice chiral gauge theories, (iii) Fermion algorithms, (iv) Short distance properties of non-asymptotically free couplings like $U(1)$ gauge coupling, Yukawa coupling & the scalar field quartic self-coupling, (v) Fermion doubling in transverse lattice light front field theory, (vi) Lower dimensional field theories, (vii) Lattice QCD with two flavours of dynamical quarks: topology and chiral regime, (viii) Non-perturbative gauge fixing of compact Abelian and non-Abelian lattice gauge fields.

Recent Highlights of Research: Topology & chiral regime of Lattice QCD
SINP Kolkata lattice group has done the first major investigation in India of lattice QCD with light dynamical quarks at zero temperature using parallel supercomputers. Two light degenerate flavours of naive Wilson quarks were used. Our results have shown unambiguously, for the first time in lattice QCD with Wilson quarks, the suppression of the topological susceptibility with decreasing quark mass, a result that is consistent with chiral Ward identity and chiral perturbation theory. Our results are obtained for two lattice spacings and three lattice volumes. Only one other group (MILC) has results of this suppression at more than one lattice spacing, albeit with highly improved staggered quarks and a decade of running. In order to understand the suppression, a thorough study of the topological charge density correlators was carried out. In addition, first systematic study of autocorrelations of relevant operators were also undertaken in lattice QCD with light quarks.

The demonstration of the suppression of the topological susceptibility in QCD with decreasing light quark mass has been recognised as a major achievement. Our work is highlighted in a plenary talk titled “Recent lattice results on topology” very prominently by M. Mueller-Preussker at the 32nd International Symposium LATTICE 2014, Columbia University, USA, 23 - 28 June 2014.

Current Research & Future Outlook: Gauge-fixing of compact gauge fields
This is the subject of my current and immediate future investigation with my student Mugdha Sarkar. For non-Abelian gauge theories, we are implementing a so-called equivariant BRST (eBRST) scheme for numerical investigation, since usual BRST symmetry is untenable with compact gauge fields leading to zero partition function. For the Abelian gauge-fixing part, we have investigated the strong gauge coupling region with a higher derivative term for the gauge fixing (breaking BRST), and have shown that the longitudinal gauge degrees of freedom decouple from the physical sector of the theory, in the same way they decouple for weak gauge couplings. We hope, some of our techniques to be used to track the change of sign of the ghost determinant in the non-Abelian case will be of interest to the lattice QCD community as well.

Palash Baran Pal, Senior Professor H+

DoB 04/09/1955

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Education

1983: Ph.D, Physics, Carnegie-Mellon University, Pittsburgh, USA
1977: M.Sc, Physics, Calcutta University, Calcutta, India
1975: B.Sc, Physics, Calcutta University, Calcutta, India

Academic Positions

2011 – : Senior Professor H+, Saha Institute of Nuclear Physics
2007 – 2011: Senior Professor H, Saha Institute of Nuclear Physics
2004 – 2007: Professor G, Saha Institute of Nuclear Physics
1999 – 2004: Professor F, Saha Institute of Nuclear Physics
1997 – 1999: Professor E, Saha Institute of Nuclear Physics
1994 – 1997: Professor E, Indian Institute of Astrophysics, Bangalore
1992 – 1994: Post-Doctoral Research Associate, University of Texas, Austin, USA
1989 - 1992: Post-Doctoral Research Associate, University of Oregon, Eugene, USA
1986 - 1989: Post-Doctoral Research Associate, University of Massachusetts, Amherst, USA
1984 - 1986: Post-Doctoral Research Associate, University of Maryland, College Park, USA

Awards / Honours

Rabindra Smriti Puroskar for scientific writing in Bengali.
RamendraSundar Puroskar for scientific writing in Bengali.
Visiting positions in various institutes around the world, e.g., University of Puerto Rico (Ro Piedras, Puerto Rico), École Polytechnique (Palaiseau, France) International Centre for Theoretical Physics (Trieste, Italy), Instituto Superior Teécnico (Lisbon, Portugal)

Selected Publications (since 2012)

Lepton number violating effects in neutrino oscillations
Sebastian Hollenberg, Octavian Micu, Palash B. Pal; *Phys.Rev. D85 (2012) 053004*.

Scalar sector properties of two-Higgs-doublet models with a global U(1) symmetry
Gautam Bhattacharyya, Dipankar Das, Palash B. Pal, M.N. Rebelo; *JHEP 1310 (2013) 081*.

Number of fermion generations from a novel Grand Unified model
Pritibhajan Byakti, David Emmanuel-Costa, Arindam Mazumdar, Palash B. Pal *Eur.Phys.J. C74 (2014) 2730*.

An introductory course of Particle Physics
Palash B Pal. A text book on Particle Physics for post-graduate students as well as beginning researchers. 800+ pages. CRC Press, July 2014.

S_3 symmetry and the quark mixing matrix
Dipankar Das, Ujjal Kumar Dey, Palash B. Pal; *Phys.Lett. B753 (2016) 315-318*.

Coxeter groups and the PMNS matrix
Pritibhajan Byakti, Palash B. Pal; *e-Print: arXiv:1601.08063*.

Reduction formulas for symmetric products of spin matrices
P B Pal; *Rep. Math. Phys. 77 (2016) 35*.

Quark mixing in an S3 symmetric model with two Higgs doublets
Dipankar Das, Ujjal Kumar Dey, Palash B. Pal; *e-Print: arXiv:1705.07784*.

Teaching / Guidance

Supervising Ph.D thesis of six students, all of whom have got their PhD degrees
Taught regularly in SINP graduate courses
Taught courses outside, e.g., in SERC School on High Energy Physics, in Rencontres du Vietnam, Hanoi, and in various Refresher courses organized by Calcutta University and Jadavpur University.

Areas of Research

Weak interactions, with specific emphasis on neutrino physics

Beyond the standard model, including left-right symmetric model and grand unification

Particle properties in material medium, commonly (and inappropriately) known as finite temperature field theory

Particle properties in background magnetic fields

Astrophysics and Cosmology related to Particle Physics

Linearized theory of gravity

A. Harindranath, Senior Professor (Retired)

DoB 15th November, 1956.
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Education
1985: Ph.D, Physics, City University of New York (CUNY), U.S.A.
1979: M.Sc, Physics, University Centre, Calicut University, India
1977: B.Sc, Physics, Sree Krishna College Guruvayur, Kerala, India

Academic Positions
1994 - 2017: Faculty, Saha Institute of Nuclear Physics
1988 - 1994: Postdoctoral Research Associate, The Ohio State University, U.S.A.
1987 - 1988: Visiting Associate, The Ohio State University, U.S.A.
1986 - 1987: Visiting Associate, Kellogg Lab, California Institute of Technology, U.S.A.
1985 - 1986: Postdoctoral Research Associate, Iowa State University, U.S.A.
1980 - 1985: Teaching and Research Assistant, Brooklyn College of CUNY, U.S.A.

Awards / Honours
Principal Investigator (India) of the Indo-US Collaboration Project entitled *Quantum Chromo Dynamics - a light front Hamiltonian approach* jointly funded by the Department of Science and Technology, India and the U.S. National Science Foundation for a total duration of three years (April 2002 - March 2005). Principal Investigator (U.S.A) – Prof. James P. Vary.

Selected Publications

Effects of boundary conditions and gradient flow in 1+1 dimensional lattice ϕ^4 theory
A. Harindranath and Jyotirmoy Maiti
Phys.Rev. D95 (2017) no.7, 074506. https://arxiv.org/abs/1701.04601

Physical observables from boundary artifacts: scalar glueball in Yang-Mills theory
Abhishek Chowdhury, A. Harindranath and Jyotirmoy Maiti
JHEP 1602, (2016) 134. https://arxiv.org/abs/1509.07959

Correlation and localization properties of topological charge density and the pseudoscalar glueball mass in SU(3) lattice Yang-Mills theory
Abhishek Chowdhury, A. Harindranath and Jyotirmoy Maiti
Phys. Rev. D 91, 074507 (2015). https://arxiv.org/abs/1409.6459

Open Boundary Condition, Wilson Flow and the Scalar Glueball Mass
Abhishek Chowdhury, A. Harindranath and Jyotirmoy Maiti
JHEP 1406 (2014) 067. https://arxiv.org/abs/arXiv:1402.7138

Topological susceptibility in lattice Yang-Mills theory with open boundary condition
Abhishek Chowdhury, A. Harindranath, Jyotirmoy Maiti and Pushan Majumdar
JHEP 1402 (2014) 045. https://arxiv.org/abs/arXiv:1311.6599

On transverse spin sum rules
A. Harindranath, Rajen Kundu and Asmita Mukherjee
Phys. Lett. B728 63 (2014). https://arxiv.org/abs/arXiv:1308.1519

Comment on "Proton Spin Structure from Measurable Parton Distributions"
A. Harindranath, Rajen Kundu, Asmita Mukherjee and Raghunath Ratabole
Phys. Rev. Lett. 111 039102 (2013). https://arxiv.org/abs/arXiv:1212.0761

Pion and nucleon in two flavour QCD with unimproved Wilson fermion
Abhishek Chowdhury, Asit K. De, Sangita De Sarkar, A. Harindranath, Jyotirmoy Maiti, Santanu Mondal and Anwesa Sarkar
Nucl. Phys. B 871 (2013) 82. https://arxiv.org/abs/arXiv:1212.0717

Exploring autocorrelations in two-flavour Wilson Lattice QCD using DD-HMC algorithm
Abhishek Chowdhury, Asit K. De, Sangita De Sarkar, A. Harindranath, Jyotirmoy Maiti, Santanu Mondal and Anwesa Sarkar
Comput.Phys.Commun. 184 (2013) 1439. http://arxiv.org/abs/arXiv:1209.3915

Many avatars of the Wilson fermion: A perturbative analysis
Abhishek Chowdhury, A. Harindranath, Jyotirmoy Maiti and Santanu Mondal
JHEP 1302 (2013) 037. https://arxiv.org/abs/arXiv:1301.0675

Topological charge density correlator in Lattice QCD with two flavours of unimproved Wilson fermions
Abhishek Chowdhury, Asit K. De, A. Harindranath, Jyotirmoy Maiti and Santanu Mondal
JHEP 1211 (2012) 029. https://arxiv.org/abs/arXiv:1208.4235.

Topological susceptibility in Lattice QCD with unimproved Wilson fermions
Abhishek Chowdhury, Asit K. De, Sangita De Sarkar, A. Harindranath, Santanu Mondal, Anwesa Sarkar and Jyotirmoy Maiti
Phys. Lett. B707 (2012) 228. https://arxiv.org/abs/1110.6013.

Teaching / Guidance Under my guidance, Santanu Mondal received Ph. D degree from Calcutta University in 2013 and Abhishek Chowdhury received Ph. D degree from Homi Bhabha National Institute in 2014.

Areas of Research Light front field theory, Quantum Chromodynamics

Essential Strength of Research:

I work on elucidating high energy phenomena on the basis of light front field theory and investigating various issues of current interest in lattice field theory. In the field of high energy phenomena we have clarified several issues in transverse spin sum rules relevant for polarized deep inelastic scattering. In lattice QCD we have established the validity of unimproved Wilson fermions together with unimproved gauge action. We have further explored the effectiveness of open boundary condition and gradient flow in four dimensional SU(3) lattice Yang-Mills theory and two dimensional lattice ϕ^4 theory.

Future Research Plan:

I retired from SINP in November 2016.

Anjan Kundu, Professor H^+

DoB 24.01.1953

Passed away on 31.12.2016

Education 1981: PhD (Phys-Math Sc), Patrice Lumumba University, Moscow, USSR

Academic Positions
1985 - 2016: Saha Institute of Nuclear Physics
1981 - 1983: Postdoctoral Fellow, Joint Institute of Nuclear Research (JINR), Dubna (Moscow)

Awards / Honours
PDF- JINR, Dubna (Moscow), Lecturer - BITS (Pilani)
Fellow of INSA (Indian National Science Academy) from 2014
Fellow of IASc (Indian Academy of Sciences) from 2015
Member of Editorial Board of the Proc Roy Soc (Lon): ser. A (PRSL A) (2014-2016)
Humbolt Foundation Fellow (Germany) 1994-1999
Senior Associate ICTP (Trieste, Italy) (2006-2013)
External Expert for City Univ London
Visiting Scientist: Bonn U, U Kassel, Hannover U,Dortmund U, Wuppertal U, Rome U, Ohio State U,N.Carolina U, Arizona State U, ANU (Australia), Prague Tech U
Member American Math Soc, IPS

Selected Publications

Exact asymmetric Skyrmion in anisotropic ferromagnet and its helimagnetic application: Anjan Kundu. *Nucl. Phys. B909 (2016) 73-85.*

Exact Bethe ansatz solution of a nonlinear quantum field model in quasi-two dimensions linked to the Landau-Lifshitz equation: Anjan Kundu. *Nucl. Phys. B913 (2016) 1-14.*

Lagrangian and Hamiltonian structures in an integrable hierarchy and spacetime duality: Jean Avan (Cergy-Pontoise U., LPTM), Vincent Caudrelier (London, City U.), Anastasia Doikou (Heriot-Watt U.), Anjan Kundu (Saha Inst.). *Nucl. Phys. B902 (2016) 415-439.*

Construction and exact solution of a nonlinear quantum field model in quasi-higher dimension: Anjan Kundu. *Nucl. Phys. B899 (2015) 1-13.*

Novel Hierarchies & Hidden Dimensions in Integrable Field Models: Theory & Application: Anjan Kundu. *J. Phys. Conf. Ser. 482 (2014) 012022.*

Teaching / Guidance One student (Avik Mukherjee) has been awarded PhD degree in 2016.

Areas of Research Classical and quantum exactly solvable models.

Essential Strength of Research:

Topological skyrmions as intricate spin textures were observed experimentally in 2d helimagnets. That such solitonic states appear as exact solutions in pure ferromagnets was shown by Belavin and Polyakov (BP). In (1) an innovative generalization of the BP solution has been proposed for anisotropic ferromagnets. The proposal is based on a geometric inequality that maps skyrmions to a new class of functions. The possibility of stabilizing such metastable states in helimagnets has also been discussed.

Integrable quantum field models are known to exist mostly in one space dimension. In (2) exploiting the use of multi-time in integrable systems and a Lax matrix of higher scaling order, a novel interacting quantum field model in quasi-two dimensions has been constructed. The Yang-Baxter integrability is proved for the model by finding a new kind of commutation rule for its basic fields. In spite of a close link with the quantum Landau-Lifshitz equation, the present model differs widely from it, in its content and in the results obtained. Using the algebraic Bethe ansatz the eigenvalue problem of this quantum field model has been solved exactly for all its higher conserved operators. The idea presented here should instigate the construction of a novel class of integrable field and lattice models and exploration of a new type of underlying algebras.

In (3) a novel notion of dual integrable hierarchies has been proposed, based on the notion of the nonlinear Schrödinger (NLS) hierarchy. For each integrable nonlinear evolution equation (NLEE) in the hierarchy, dual integrable structures exist by the fact that the zero-curvature representation of the NLEE can be realized by two Hamiltonian formulations stemming from two distinct choices of the configuration space, yielding two inequivalent Poisson structures on the corresponding phase space and two distinct Hamiltonians. This is fundamentally different from the standard bi-Hamiltonian or generally multi-time structure. The first formulation chooses purely space-dependent fields as configuration space; it yields the standard Poisson structure for NLS. The other one is new: it chooses purely time-dependent fields as configuration space and yields a different Poisson structure at each level of the hierarchy. The corresponding NLEE becomes a space evolution equation. The role of the Lagrangian formulation as a unifying framework for deriving both Poisson structures has been emphasized, using ideas from covariant field theory. One of the main result is to show that the two matrices of the Lax pair satisfy the same form of ultralocal Poisson algebra (up to a sign) characterized by an r-matrix structure, whereas traditionally only one of them is involved in the classical r-matrix method. We construct explicit dual hierarchies of Hamiltonians, and Lax representations of the triggered dynamics, from the monodromy matrices of either Lax matrix. An appealing procedure to build a multi-dimensional lattice of Lax pair through successive uses of the dual Poisson structures has been briefly introduced.

Nonperturbative exact solutions are available for several quantum integrable models in one space dimension. In (4) a novel nonlinear Schrödinger quantum field model has been constructed in quasi-two dimensions using an alternative to the Lax matrix approach and exploiting the hidden multi-space-time concept in integrable systems. An intriguing field commutator has been discovered, confirming the integrability of the model and yielding its exact Bethe ansatz solution with rich scattering and bound-state properties. The universality of the scheme is expected to cover diverse models, opening up a new direction in the field.

Parthasarathi Mitra, Professor H+ (Retd on Sep. 30, 2016)

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Education

1981: Ph.D, Physics, Bombay University, Bombay, India
1973: M.Sc, Physics, Calcutta University, Calcutta, India
1971: B.Sc, Physics, Calcutta University, Calcutta, India

Academic Positions

1989 - 2016: Reader - Professor H+, Saha Institute of Nuclear Physics
1986 - 1989: Reader, North Bengal University, Siliguri
1984 - 1986: Pool Officer, Saha Institute of Nuclear Physics, Calcutta
1983 - 1984: Postdoctoral Fellow, Dalhousie University, Halifax, Canada
1981 - 1983: Alexander von Humboldt Fellow, Hamburg University, Hamburg, Germany

Awards / Honours

Fellow, Indian National Science Academy
Fellow, National Academy of Sciences, India

Selected Publications

"Fermion Regularization, Fermion Measure and Axion Fields"
P. Mitra
e-Print Archive: *1504.07936v2*

"Quantum and Classical Areas of Black Hole Thermodynamics"
Amit Ghosh and P. Mitra
Class. Quant. Grav. 32 (2015) 165006

"Absence of Log Correction in Entropy of Large Black Holes"
Amit Ghosh and P. Mitra
Phys. Lett. B734 (2014) 49

"Area Law for Black Hole Entropy in the SU(2) Quantum Geometry Approach"
P. Mitra
Phys. Rev. D85 (2012) 104025

Teaching / Guidance

Taught in SINP graduate courses

Areas of Research

Loop Quantum Gravity, Strong CP

Essential Strength of Research:

I worked in black hole physics using the Loop Quantum Gravity approach to compute black hole entropy and showed **with Amit Ghosh** that the logarithmic corrections depend on the classical area rather than the area eigenvalue.

I worked on strong CP with and without axions and demonstrated the importance of regularizing the fermion action, which led to the unexpected result that a γ_5 phase in the quark mass term is not equivalent to a CP violating $F\tilde{F}$ term.

Research Areas: Theory Division

This is a brief account of the research areas, mostly of the recent past, pursued at the Theory Division, some of the major contributions made, and possible future directions. Research at the Theory Division covers an wide area of High and Medium Energy Physics, including more formal aspects of space-time and the fundamental constituents, and some aspects of Mathematical Physics. The account below is put together from individual contributions, and hence is not always homogeneous in style and extent of exposition.

1 Particle Phenomenology

1.1 Beyond Standard Model (BSM) Physics

Work has been done in the area of 'Physics Beyond the Standard Model of particle physics' over last several years. In particular, some of the contributions are:

Z-boson Physics: (a) LEP limits on vector-like fermions, additional gauge bosons, and supersymmetric particles using the precision electroweak observables; (b) Constraints on the oblique electroweak parameters S,T,U using the full profile of the Z-boson and implications on the number of chiral families.

Supersymmetric models: (a) New limits on baryon and lepton number violating couplings using accelerator and non-accelerator data; (b) Analysis of naturalness constraints on gauge-mediated supesymmetry.

Extra-dimensional Models: (a) Calculation of contributions of Kaluza-Klein neutrinos to neutrinoless double-beta decay, (b) Classification of generic higher-dimensional models according to their high-scale sensitivities, (c) Comprehensive numerical analysis of brane-world induced supersymmetry breaking.

Multi-Higgs models: (a) Various flavor models controlled by discrete symmetries imply the presence of multiple scalar multiplets – studying their properties in the light of Higgs boson data. (b) Studying the properties of the two-Higgs-doublet models in detail.

Future Research Plan:
Probing Physics Beyond the Standard Model from an interplay between accelerator and non-accelerator data. More specifically, exploring the parameter space of BSM physics using data from Higgs production and decays at LHC, flavor-physics oriented experiments, as well as cosmology. Main focus would be on composite Higgs models.

1.2 Radiative Corrections of QCD

Perturbative aspects of QCD and its application to high energy scattering processes, involves deeper understanding of perturbative structure of multi-loop and multi-leg QCD amplitudes which constitute the higher order QCD radiative corrections to various observables at hadronic colliders such as LHC. At the hadron colliders, the incoming states being protons, QCD plays an important role in the production mechanism of particles in the SM as well as in any physics beyond the Standard Model. In the context of the extra dimensional models this involved computation of quark and gluon form factors to 2 and 3 loop order in QCD for universal and non-universal coupling to a spin-2 or a pseudo-scalar Higgs boson.

Another aspect that is important at the colliders is combining fixed order perturbative results and the parton shower Monte Carlo (PS) can cover most of the kinematical regions in order to consistently include resummation in the collinear limit and also allow us to study more exclusive final states and provide predictions as realistic as possible to the experimental situations.

Main research focus in the past few years has been on precision physics at the LHC. To fully benefit from the experimental program at the LHC, precise theoretical predictions for both signals of new physics and SM background are very essential. State-of-the-art quantum field theoretical techniques are used to compute higher order QCD corrections to observables at the LHC.

Some of the important recent contributions are:

(a) We performed the very first calculation involving a massive spin-2 particle at NNLO level in QCD for the production of a pair of leptons at hadron colliders, wherein the massive spin two could couple to the SM *via* a universal energy-momentum tensor or via a non-universal couplings. The corrections are not only large but also important to stabilise the predictions with respect to the unphysical renormalisation and factorisation scales.

(b) We computed the three-loop massless QCD corrections to the quark and gluon form factors of pseudo-scalar operators. The three-loop corrections to the pseudo-scalar form factors are an important ingredient to precision Higgs phenomenology.

(c) Higgs Characterisation: Effective field theory approach is one the powerful methods to study the characterisation of the Higgs boson discovered at the LHC. Given that there are large number of higher dimensional operators, a systematic approach in an automated framework is essential. Using MadGraph 5 and aMC@NLO, we have incorporated relevant higher dimensional operators along with next to leading order QCD effects to study spin and parity properties of the Higgs boson.

Future Research Plan:

With the absence of any signal of new physics at the LHC, searches of physics beyond the Standard Model (BSM) is based on the ability to make very precise theoretical predictions within the SM and to look for possible deviations between experimental observations and theoretical predictions, this program may yield direct or indirect evidence of physics beyond the Standard Model within estimated uncertainties. The Higgs boson discovery could be viewed as the foundation for a long-term precision physics program measuring the properties of the Higgs boson, its coupling to itself and to other elementary particles. The inclusion in the predictions of higher order quantum effects at fixed order in perturbative expansion and the resummation to all orders will improve the accuracy of important measured observables. Consequently these predictions will help constrain variety of BSM scenarios.

2 Quark Gluon Plasma(QGP)

2.1 An Account of Research Acitvity:

QGP is the strongly interacting deconfined matter which existed only briefly in the early universe, a few microseconds after the Big Bang. The discovery and characterisation of the properties of QGP remains one of the best orchestrated international efforts in modern nuclear physics. This subject is presently actively studied at particle accelerators, where one collides heavy nuclei, moving at nearly the speed of light, in order to produce in the laboratory this hot and dense state of matter. The Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) studying the collisions of heavy nuclei at relativistic energies continue to generate a wealth of data which is being analysed to provide valuable information about the nature of the ephemeral matter thus created. This calls for a better theoretical understanding of particle properties of hot and dense deconfined matter, which reflect both static and dynamical properties of QGP. The hot and dense matter produced in high energy heavy-ion collisions is a many particle system that seeks theoretical tools from an interface of particle physics and high energy nuclear physics. This requires the systematic use of QCD methods (both perturbative and non-perturbative) with a strong overlap from (i) Finite temperature and density field theory, (ii) Relativistic fluid dynamics, (iii) Kinetic or transport theory, (iv) Quantum collision theory, (v) String theory and (vi) Statistical mechanics and thermodynamics. Various aspects of QGP by using phenomenology, perturbative and nonperturbative methods of QCD have very actively been pursued, which are briefly noted: (i) Thermodynamics using perturbative and nonperturbative approach (ii) Chemical equilibration of QGP (iii) Current-current correlation function, its electromagnetic spectral representation and spectral properties, e.g., electromagnetic emissions, transport coefficients, conserved density fluctuations etc. (iv) Energy loss of partons (both collisional and radiative) (v) Jet quenching (vi) Recombination aspect of hadronization of QGP (vii) Fluidity aspect of QCD matter (viii) Dynamical Screening (ix) Wake phenomena of QGP (x) Susceptibilities associated with fluctuations of conserved number density, both in perturbative and nonperturbative approach (xi) Properties of magnetized QCD medium etc.

2.2 Important Highlights:

Propagation of Heavy quarks in QGP:
Heavy quarks are produced in very early time from hard scattering of partons in nucleons and their distribution is frozen. Immediately upon their production they will propagate in the plasma, interact with thermalized degrees of freedom in it and lose energy through collisions and radiations. Some very important and pioneering contributions on heavy quark propagation have been done and the impact of which is very evident as it has become an independent area of research by its own merit.

Radiative and collisional jet energy loss in the quark-gluon plasma:
A consistent formalism for obtaining both collisional and radiative energy-loss distribution within a single framework was lacking in the literature. For the first time a consistent formalism using Fokker-Planck dynamics was formulated to obtain light quark energy-loss distributions that accounts for the probabilistic nature of the jet energy-loss, for both collisional and radiative one in a single framework. When applied to light quark the nuclear suppression factor (quenching) has been found to be in very good agreement with RHIC data. This formalism was then applied to heavy-quarks by others in the community.

Chemical equilibration of Quark-Gluon Plasmas:
QGP is a multi-partonic system which is produced initially far away from both thermal and chemical equilibrium. It is believed that the partons inside such a system will then further interact with each other and eventually establish the thermal equilibration, but the chemical equilibration will depend on the time available to the partonic system before perturbative QCD is no longer applicable. For the first time, it was demonstrated that it is essential to understand the extent of chemical equilibration of partons in an expanding plasma before one can draw any reliable conclusions about electromagnetic radiations (photon and dilepton), propagation of heavy quarks and strangeness production from plasma, transport coefficients of plasma, energy-loss of energetic partons and jet quenching in plasma, etc.

Three-loop QCD Pressure at finite temperature and chemical potential:
The equation of state is a generic quantity of a hot and dense many particle system and it is required to study the expansion dynamics by using hydrodynamics of such system. A systematic computation of thermodynamic potential and thereby various thermodynamic quantities such as pressure, energy density, various orders of quark number susceptibility, trace anomaly, speed of sound, entropy density etc. of QGP within three loop (next-to-NLO (NNLO)) Hard Thermal Loop perturbation theory (HTLpt) at finite temperature and chemical potential. The results are gauge invariant, complete in strong coupling of g^5, fully analytic that does not require any free fit parameter beside renormalization scale. This NNLO (3-loop order) in HTLpt provides new estimates of a whole set of thermodynamic quantities in a remarkable accuracy, which agree very well with recent lattice QCD

results at the temperature down to 250 MeV. This NNLO calculation is important by its own merit and in particular will be very apt for the matter produced in planned FAIR GSI heavy-ion collisions. At present this calculation has drawn enormous attention to the community of heavy-ions and lattice QCD.

Future Research Plan:

The dual heavy-ion colliders at RHIC and LHC have given us opportunity to look simultaneously at the signatures of hot and dense QCD. The continuing upgrades to the RHIC and LHC program are in the line. Further, in second generation experiment, *e.g.*, FAIR, the energy range from 10 to 45 GeV/u in a fixed target with high luminosity is also to be scanned searching for (i) indications of the deconfinement phase transition at high baryon densities, which is complementary to the investigations performed at the RHIC BNL, and at the LHC CERN, (ii) the critical point providing direct evidence for a phase boundary, (iii) in-medium modifications of hadrons in dense matter, and (iv) exotic states of matter such as condensates of strange particles, charmonium production, etc. Therefore, a detailed theoretical study is required in favour of the relevant observables which are very sensitive to high density effects and phase transition.

The most important recent experimental results come from the proton lead (pA) collisions at LHC. Surprisingly, this control experiment of such a small system size appears to show signs of collective, QGP-like behavior in its low momentum particles. There is additional, non-trivial and unexpected behaviour shown by the high momentum particles, too. A major focus will be: can one describe the high momentum observables in high multiplicity pp and pA collisions using the methods of pQCD as applied in AA collisions, i.e. under the assumption of the creation of QGP in these minuscule systems? A theoretical framework is necessary to make quantitative energy loss predictions in small systems. For the next step, we want to compute the change to the Debye screening mass in finite sized plasmas. We will first perform the calculation in a scalar field theory with Dirichlet boundary conditions. As a first step, we plan to compute the usual thermodynamic quantities of the energy density, pressure, etc. in this scalar field theory. Then we will graduate to gauge theories, for which maintaining the gauge invariance in a finite sized system will need to be understood. Finally, on the purely theoretical side, we will then use our new-found thermal field theory knowledge to compute the energy loss of a high energy parton in a finite size plasma of dynamical scattering centres. Then implement these new energy loss formulae in an energy loss model to compute predictions for the suppression of high momentum particles in high multiplicity pp, pA, and AA collisions.

A captivating nature of non-central heavy ion collisions indicates that a very strong anisotropic magnetic field is generated in the direction perpendicular to the reaction plane, due to the relative motion of the ions themselves. The initial magnitude of this magnetic field can be very high at RHIC and LHC energies at the time of the collision and then it decreases very fast. The presence of an external anisotropic field in the medium subsequently requires modification of the present theoretical tools that can be applied appropriately to investigate various properties of QGP. Investigation of various properties of hot and dense magnetized QCD matter and its evolution using magnetohydrodynamics would be very useful and interesting.

3 Non-perturbative Studies: Quantum Field Theory (QFT) on Lattice

In the past, QFT on the lattice regulator at the Theory Division involved a few formal aspects involving: (i) Chiral Gauge Theory using Domain-Wall Fermions, (ii) Fermion-doubling of the Transverse Lattice Light Front Field Theory, (iii) Non-perturbative study of the $U(1)$ gauge coupling, (iv) Study of lower dimensional scalar field theory, topological kinks and renormalisation, (v) Analytical study of approach to chiral anomaly with a variety of improved lattice fermions, etc. In the last decade, in addition, we have been involved in a few fundamental aspects of lattice QCD, namely scale setting, its chiral regime, topological sectors, and validity of unimproved Wilson fermions. For the past years, efforts are also underway to test proposals of non-perturbatively gauge-fixed compact lattice gauge fields, both Abelian and non-Abelian. In addition to providing a definition of lattice chiral gauge theories, the gauge-fixing approach in a generalised BRST-like scheme aims to provide a satisfactory and general formalism for gauge theories.

Recent Highlights of Research (Topology and chiral regime of Lattice QCD):

SINP Kolkata lattice group has done the first major investigation in India of lattice QCD with light dynamical quarks at zero temperature using parallel supercomputers. Two light degenerate flavours of naive Wilson quarks were used. Our results have shown unambiguously, for the first time in lattice QCD with Wilson quarks, the suppression of the topological susceptibility with decreasing quark mass, a result that is consistent with chiral Ward identity and chiral perturbation theory. Our results are obtained for two lattice spacings and three lattice volumes. Only one other group (MILC) has results of this suppression at more than one lattice spacing, albeit with highly improved staggered quarks and a decade of running. In order to understand the suppression, a thorough study of the topological charge density correlators was carried out. In addition, first systematic study of autocorrelations of relevant operators were also undertaken in lattice QCD with light quarks.

The demonstration of the suppression of the topological susceptibility in QCD with decreasing light quark mass has been recognised as a major achievement. Our work is highlighted in a plenary talk titled "Recent lattice results on topology" very prominently by M. Mueller-Preussker at the 32nd International Symposium LATTICE 2014, Columbia

University, USA, 23 - 28 June 2014.

To summarise, in lattice QCD we have established the validity of unimproved Wilson fermions together with unimproved gauge action. We have further explored the effectiveness of open boundary condition and gradient flow in four dimensional $SU(3)$ lattice Yang-Mills theory and two dimensional lattice ϕ^4 theory.

In the field of high energy phenomena, probed with techniques of light front field theory, we have clarified several issues in transverse spin sum rules relevant for polarised deep inelastic scattering.

Current Research & Future Research Plan (Gauge-fixing of compact gauge fields):
This is the subject of the current and immediate future investigation. For non-Abelian gauge theories, we are implementing a so-called equivariant BRST (eBRST) scheme for numerical investigation, since usual BRST symmetry is untenable with compact gauge fields leading to zero partition function. The eBRST is essentially a gauge-fixing of a coset space, leaving a non-trivial subgroup of the gauge group invariant. Nil-potency of usual BRST is replaced by gauge-variation of the subgroup for double variation of the eBRST. These theories essentially involves a four-ghost self-interaction term.

For the Abelian gauge-fixing part, we have investigated the strong gauge coupling region with a higher derivative term for the gauge fixing (breaking BRST), and have shown that, as the gauge symmetry is recovered by tuning a parameter, the longitudinal gauge degrees of freedom decouple from the physical sector of the theory, in the same way they decouple for weak gauge couplings.

We hope, some of our techniques to be used to track the change of sign of the ghost determinant in the non-Abelian case will be of interest to the lattice QCD community as well.

4 Cosmology

4.1 Research Activities

Looking at physics through cosmology at very high energy and large distances, not only allows us to understand the origin of the Universe, but also provides a unique source to get an insight into the fundamental laws of nature, such as the important role of gravity and the particle interactions. A plethora of data over the last several decades have confirmed the Standard Model of particle physics with an extremely high precision. However, the SM does not answer some of the fundamental questions about nature. We are now expecting to find 'new physics' around the TeV energy scale at the Large Hadron Collider. On the other hand, only during the last one and a half decade, the cosmological observations (e.g CMB measurements by PLANCK) have produced increasing amounts of good quality data, allowing us to test cosmological models against observations. Consequently, a cosmological standard model is also emerging nicely where the Universe seems to have started with an exponential growth as in the inflationary paradigm, followed by a hot big bang expansion. At the same time, the recent observations of present cosmic acceleration have infused great interest in finding ideas capable of explaining this phenomenon.

The next years are certainly going to be very exciting in the fields of cosmology and particle physics. Over the years, both the fields have reached to a stage where the advancement in one field plays a vital role in shaping the ideas in the other field. Consistency checks have become essential to have a coherent cosmological evolution of the Universe.

4.2 Important Highlights

Inflation model building in supergravity and String Theory: Typically, inflation is assumed to have occurred at some very high energy scale and in its simplest realization, a single scalar field is responsible for its dynamics. Supergravity, arising also as the low energy limit of string compactifications, is a promising theoretical framework to describe inflation: providing numerous (complex) scalar fields potentially suitable for inflation, it also consistently accounts for the Planck-suppressed corrections to global supersymmetry, which can no longer be simply neglected at the high energy scales of inflation. Supergravity model building for inflation has remained an active area of research over the years. In particular, tribrid inflation model has been proposed, and its phenomenological consequences have been worked out in several works. Tribrid inflation is a variant of supersymmetric hybrid inflation where three fields are involved and where the inflaton field resides in the matter sector of the theory. The idea of N-flation where multiple scalar fields drive inflation has been worked out in a concrete set-up of String Theory. Additionally, the issues related to inflation in the Jordon frame supergravity, solution to the η-problem using symmetry, and constructing models with high scale of inflation with low energy supersymmetry breaking have been worked out.

Relating post-inflationary history of the Universe with inflationary observables: The predictions for all the cosmological observables of any inflationary model depend on the number of e-foldings during inflation which is sensitive to the post-inflationary history of the universe. In physics beyond the standard model (Supergravity / String Theory), the generic presence of gravitationally coupled light scalar fields (e.g moduli in String Theory) 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. In a series of works, this effect has been explored in detail, and found that understanding the details of post-inflationary physics including reheating is crucial for future precision measurements of scalar spectral index n_s with projected sensitivity of $\Delta n_s \sim 0.001$.

String landscape phenomenology: Several aspects of string landscape scenario, and its phenomenological and cosmological implications have been analysed. An attempt has made to understand the phenomenology of quark and lepton masses in the context of String Theory landscape picture. In this set-up, exploration related to the issue of initial condition for inflation has been also discussed. It has been shown that the overshoot problem in inflation after tunneling, i.e. inflation in an open universes, is not severe as it is usually perceived in the literature. In the Universe populated by quantum tunneling, the analysis shows that the small-field and the large-field inflation have parametrically the same volume of phase space of initial conditions.

Phenomenology of modified gravity theories: Although $f(R)$ modification of late time cosmology is successful in explaining present cosmic acceleration, it is difficult to satisfy the fifth-force constraint simultaneously. Even when the fifth-force constraint is satisfied, the effective scalar degree of freedom may move to a point (close to its potential minima) in the field space where the Ricci scalar diverges. This point has been elucidated further with a specific example of $f(R)$ gravity that incorporates several viable $f(R)$ gravity models in the literature. In particular, it has been shown that the nonlinear evolution of the scalar field in pressureless contracting dust can easily lead to the curvature singularity, making this theory unviable. Other aspects of modified gravity related to Horava-Lifshitz $f(R)$ Gravity, inflationary attractor models in the context of scalar-tensor theories have been also explored.

Phenomenology of inflation and dark energy: The physics of inflation and dark energy has striking similarity, but with different scales. Several phenomenological aspects of inflation and dark energy have been explored, and it includes neutrino dark energy, modified pNGB dark energy, explaining anomalies in the cosmic microwave background data etc.

Future Research Plan

In future, physics at the interface of cosmology and particle physics would be explored further. Without violating any cosmological observation, the Universe could have been matter dominated all the way up to the MeV energy scale. It would be interesting to find a strategy in probing this epoch further. In particular, the effects on the formation of cosmological structures and future CMB distortion maps would be crucial probes. Another important area is the production of gravitational wave during and after inflation. The amplitude of gravitational wave produced during inflation is parametrised by the observable tensor-to-scalar ratio r. The CMB measurements have an upper limit of $r < 0.11$. But, in the presence of non-canonical terms like Chern-Simons term or $\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$ in the Lagrangian, the production of gravitational wave (with chiral helicity) is changed considerably. This is an interesting avenue of research to be explored further. The existence of light scalar fields other than the inflaton can also modify the gravitational wave production at the end of inflation. In future, some aspects of constraining inflation models using cosmological data would be also explored further. The work along this direction is already in progress in the context of warm inflation and the scenario of open inflation.

5 Nuclear Theory

Research highlights:

The infinite nuclear matter is characterized by the nuclear constants, like, incompressibility coefficient, symmetry energy coefficient and their density derivatives. The nuclear constants are fundamentally important in determining the bulk properties of finite nuclei and neutron stars and yet some of them are only poorly known. The only way one can access the information about these nuclear constants is through their correlations with various bulk properties of the finite nuclei and neutron stars. One does not know a priori the existence of these correlations. The main focus of the research works is to identify the presence of strong and model independent correlations of various nuclear constants with the nuclear and neutron star observables. The nuclear Density Functional Theory is used with several accurately calibrated non-relativistic and relativistic energy density functionals. To assess the degree of correlation between nuclear observables and to explore systematic and statistical uncertainties on theoretical predictions, the chi-square statistical covariance technique is employed.

Parity-violating electron scattering provides a model-independent determination of the nuclear weak-charge form factor that has wide spread implications across such diverse areas as fundamental symmetries, nuclear structure, heavy-ion collisions, and neutron-star structure. The impact of precise measurements of the weak-charge form factor of ^{48}Ca and ^{208}Pb on the neutron skin thickness is assessed. The neutron-skin thickness is an important observable as it is strongly correlated with the slope of the symmetry energy at the saturation density. The strong correlation is found between the weak-charge form factor and the neutron radius, which accurately determines the neutron skin of neutron-rich nuclei. The optimal range of the momentum transfer 'q' is determined that maximizes the information content of the measured weak-charge form factor. Accurate measurements of the weak-charge form factor of ^{48}Ca and ^{208}Pb is proposed to have a profound impact on many aspects of nuclear theory and hadronic measurements of neutron skins of exotic nuclei at radioactive-beam facilities.

The strong and model independent correlations of neutron star radii with the linear combination of the slopes of the nuclear matter incompressibility coefficient and symmetry energy coefficient are reported for the first time. Such correlations are found to be more or less independent of the neutron star mass over a wide range. This correlation is traced back to be linked to the empirical relation existing between the star radius and the pressure at a nucleonic density between one and two times saturation density, and the dependence of the pressure on the nuclear matter incompressibility and the slope of symmetry energy. An universal correlation among various symmetry energy coefficients are also found.

Future Research Plan:
A unified nuclear energy density functional based on finite-range effective force is being developed. The derivation of such a density functional and their implementation to obtain numerical results for some test cases would result in a couple of publications by the end of next three years. Following this, the numerical calculations will be extended to realistic cases of astrophysical interest which would be important in view of the FRENA project at SINP.

6 String Theory

Past and present work:
The work done in recent times can be broadly classified as:
(a) constructions of various bound states using certain non-perturbative symmetries in string theory, (b) study of the decoupling limit and boundary theory of some of those solutions, (c) some aspects of AdS/CFT and its applications, (d) non-relativistic scaling solutions (AdS/CMT) and its applications, (e) non-supersymmetric solutions in string theory and their relations to open and closed string tachyon condensation, (f) non-supersymmetric solutions and their decoupling limit, (g) time dependent or S brane solutions in string theory and their applications in cosmology.

It is well-known that string theory possesses various non-perturbative classical symmetry group called the Cremmer-Julia U-duality group and one can use this symmetry group to generate new solutions of string theory from the known ones. Using these non-perturabative symmetry we have constructed many new solutions to string theory. Some of these solutions have been used to study different non-gravitational theories (like non-commutative YM theory, non-commutative open string theory) that exist on the (boundary of) brane bound states. These bound states are non-threshold and preserves 1/2 of the space-time susy of the string theory. We have also constructed various non-supersymmetric time-dependent (S-branes) as well as static p-brane like solutions in string theory. Non-susy solutions have been used to study the closed string picture of the tachyon (both open and closed string) condensation in string theory. It has been shown that the static non-susy Dp branes has a decoupling limit similar to the BPS branes by which bulk gravity decouples completely from the brane. This gives a gravity dual of a non-susy gauge theory (having many properties akin to QCD) and has been used recently to study some properties of quark-gluon plasma at finite temperature. We have also constructed some new bound states preserving 1/4 susy and found that they give some scaling solution (Lifshitz solution with hyperscaling violation) relevant for certain many body systems at quantum criticality. We have computed entanglement entropies for those systems to identify various phases of matter and studied some known properties of condensed matter systems. S-brane solutions have been used to obtain de Sitter solutions upto a conformal factor and also Kasner solution at early time with expansions in all three spatial directions and an anisotropic accelerating cosmology at late times with of the order of one e-folding.

In AdS/CFT holography, recently the Lifshitz vacua with broken Lorentzian symmetry, have become useful tool to study critical phenomenon in the boundary nonrelativistic theory. We have obtained new supersymmetric Lifshitz vacua, $Lif^{z=3}$, having dynamical exponent $z = 3$ in type IIB string theory, and the $Lif^{z=\frac{5}{2}}$ Lifshitz vacua of 11-dimensional M-theory. The former vacua can also be recognised as $z = 3$ and $\theta = 1$ 'hyperscaling' Lifshitz vacua in four dimensions. Various IR properties and Lifshitz to AdS RG-flows of such solutions have also been studied by us subsequently. Our solutions describe RG flow from $z = 3, \theta = 1$ $4D$ Lifshitz fixed point in IR to a $z = 1, \theta = -1$ relativistic geometry in the UV. Very recently, we have successfuly embedded the much known $4D$ Lifshitz $z = 2$ vacua of Einstein-Proca model in 10-dimensional massive Romans supergravity. The corresponding $10D$ solution is now described as $Lif_4^{z=2} \times S^1 \times S^5$. It is constituted by $D2 - D8$ branes which are nested with 'massive' string field.

We have also calculated the entanglement entropy for CFT subsystems (mainly strip subsystems) on the boundary of the 'boosted' AdS_{d+1} black branes. We needed to renormalize (redefine) the thermodynamic quantities, such as 'entanglement temperature' (length) and chemical potential etc so that the first law can exist. We have also studied holgraphic theory describing M5 branes. We found that the known $5D$ super-Yang-Mills theory of D4 branes can be lifted to $6D$ by introducing an auxiliary Abelian vector field.

Further, various issues of strongly coupled physics, in the context of Gauge-String duality, were explored. Specifically, on three broadly divided areas of research: Infrared physics for finite density systems, dynamical issues in strongly coupled dynamics, and condensed-matter-inspired systems in holography.

A new and a large class of general candidate ground states, in terms of dual geometries, were obtained as solutions of supergravity with explicit brane (or string) sources. This corresponds to dual quantum field theories with arbitrary number of adjoint and fundamental degrees of freedom, placed at a non-vanishing density. These particular solutions are inherently non-perturbative in the ratio of number of flavour and number of colour.

A holographic system that models the process of thermalisation in a strongly coupled quantum field theory, with a non-vanishing chemical potential, were analysed. It was observed, among other things, that there exist two inequivalent regimes of thermalisation, which can subsequently be interpreted as "classical" and "quantum" in a certain sense, in which the thermalisation time exhibits qualitatively different behaviour.

A truncation of four-dimensional maximal gauged supergravity, which provides the minimal ingredients of a candidate so-called holographic superconductor, was constructed. It was also pointed out that top-down versus bottom-up approaches in this field are distinct, with the example of the construction described above.

Future Research Plan:

Our recent study of graviton scattering on non-susy Dp branes and also the calculation of graviton scattering cross-section show that the bulk gravity decouples from the brane just as what happens for the BPS branes. This is one of the stepping stones for the AdS/CFT conjecture of Maldacena for the BPS branes. But if this happens for the non-susy branes then this would imply that it might be possible to obtain AdS/CFT type correspondence even for the non-supersymmetric cases. Indeed for non-susy D3 brane the explicit decoupling limit and the corresponding throat geometry has been obtained when the charge of the non-susy D3 brane is very large i.e., near the extremality. This geometry can be thought of as the holographic dual to a non-susy gauge theory on the boundary. So, using this geometry one can study the properties of QGP corresponding to non-susy Yang-Mills theory. Presently this problem is being studied and some preliminary results have been obtained. It would also be interesting to work out the detail decoupling limit of other Dp branes when $p \neq 3$. This is one of the future programs. After obtaining the decoupled geometry the properties of QGP in other dimensions can be studied. These geometries are either asymptotically AdS or conformal to AdS. So, one can think of them as some excited states of AdS geometry. Therefore it would be interesting to compute the entanglement entropy, complexity of these systems and also their connections to fidelity susceptibility relevant in the quantum information theory. One can introduce fundamental matter by introducing flavor branes in the non-susy background and try to see chiral symmetry breaking, glueball and meson spectra in various dimensions and compare those results obtained from Witten's QCD models or Sakai-Sugimoto model. BPS branes of string theory are known to be stable under small perturbation of the metric. However, the black branes are not stable and suffers from Gregory-Laflamme instability under small metric perturbation. However, the instability goes away as we go near the extremality. Similarly it would be interesting to see what happens for the non-susy branes. So, another future program includes the study of gravitational stability of the non-susy branes. However, since in the decoupling limit the solution goes near the extremality, the stability should be restored like near-extremal black branes.

More future work will be based on the continuation of the ongoing projects. Recently, the Lifshitz and Schrödinger type vacua with broken Lorentzian symmetry, were construted. These have become useful to holographically study strongly coupled critical phenomenon in the boundary nonrelativistic theory. It will be worthwhile to further study the Lifshitz vacua $Lif_4^{z=2} \times S^1 \times S^5$ and its T-dual vacua and explore dual field theory. These are constituted mainly by $D2-D8$ or $D0-D6$ branes nested with 'massive' B field. The massive string like extended excitations can be realised in respective nonrelativitic boundary theories. Further, the calculations of entanglement entropy for CFT subsystems (strip or sphecrical) on the boundary of 'boosted' AdS_{d+1} black holes can be extended to include systems where the subsystem itself lies along the boost direction. This is needed to study the velocity effects on the entanglement entropy of the small subsystems. No calculations exist beyond first order for such subsystems. We plan to study entanglement entropy for the Lifshitz solutions too. Certainly, a new supersymmetric holgraphic $6D$ theory describing M5-branes on $AdS_7 \times S^4$ is yet to be constructed. The theory presumably should be written in terms of self-dual interacting tensor fields. Interestingly, the question can be asked whether known string-like extended instanton solutions, supported by self-dual $2D$ axionic scalar and $4D$ YM gauge instantons, could be constituted by the tensor fields in such a theory.

The continued investigation of many of the issues that arise in holographic superconductors are currently being and will be pursued. For example, the non-perturbative nature of the ground state, it turns out, can also be obtained in a bottom-up description which is a much simpler story compared to supergravity with brane sources. Given this, a natural issue is to explore the bottom-up model in its own right, which is currently being pursued. For a longer term, there is an intriguing possibility that deserves careful analysis: the brane source action, in its non-Abelian form, seems naturally relevant in modeling emergence of space-time, as well as the above. Thus, a possible connection remains to be explored. Other large N gauge theories will also be pursued. Such as the SYK-model that has revived a lot of recent activities in the string theory community, supersymmetric generalizations thereof, supersymmetric gauge theories in general, specifically using the technique of localization, will be investigated. This, while still mostly in the realm of large N gauge theories, consists of a very different set of questions and techniques to rely on; and in some sense, are complementary to the Gauge-String duality approach.

7 Gravity

The work done and the contributions made therein are described below with reference to the recently published papers, as follows.

NP B889 (2014) 1-24: A quantum isolated horizon can be modeled by an $SU(2) \times SU(2)$ Chern-Simons theory on a punctured two-sphere. It is shown how a two-dimensional conformal symmetry arises at each puncture inducing an infinite set of new observables localized at the horizon which satisfy a Kac-Moody algebra. By means of the isolated horizon boundary conditions, the gravitational flux degrees of freedom are represented in terms of the zero modes of the Kac-Moody algebra defined on the boundary of a punctured disk. In this way, the construction encodes a precise notion of CFT/gravity correspondence.

Phys. Rev. D89 (2014) no.8, 084069: In loop quantum gravity the quantum states of a black hole horizon consist of pointlike discrete quantum geometry excitations called punctures that are labeled by spin j, $j = 1/2, 1, \ldots$. The excitations possibly carry other internal degrees of freedom, and the associated quantum states are eigenstates of the area operator. The appropriately scaled area operator A/l can also be interpreted as the physical Hamiltonian associated with the quasilocal stationary observers located at a small distance l from the horizon. Thus, the local energy is entirely accounted for by the geometric operator A. Assuming that close to the horizon the quantum state has a regular energy momentum tensor, the local temperature measured by stationary observers is the Unruh temperature. Degeneracy of matter states is exponential with the area $\exp(\lambda A/l^2)$ which is supported by the well-established results of QFT in curved spacetimes, which do not determine λ but only assert an exponential behavior. The geometric excitations of the horizon (punctures) are indistinguishable and in the semiclassical limit the area of the black hole horizon is large in Planck units. It follows that: Up to quantum corrections, matter degrees of freedom saturate the holographic bound. Up to quantum corrections, the statistical black hole entropy coincides with Bekenstein-Hawking entropy.

In PR D89 (2014) no 2, 024035, we derived the Bekenstein-Hawking entropy for black holes based on the near-horizon symmetries of black hole space-times. To find out these symmetries we make use of an (R, T)-plane close to a Killing horizon. We identify a set of vector fields that preserves this plane and forms a Witt algebra. The corresponding algebra of Hamiltonians is shown to have a nontrivial central extension. Using the Cardy formula and the central charge we obtain the Bekenstein-Hawking entropy.

In PR D87 (2013) no 8, 084051, in completely local settings, we established that a spherically symmetric, dynamically evolving black hole horizon can be assigned a Hawking temperature under a mild assumption. Moreover, we calculate the Hawking flux and show that the radius of the horizon shrinks in accordance with the amount of emitted flux.
In JHEP 1204 (2012) 125, we presented a new formulation of deriving Hawking temperature for near-extremal black holes using distributions. In this paper the near-extremal Reissner-Nordström and Kerr black holes are discussed. It is shown that the extremal solution as a limit of non-extremal metric is well-defined. The pure extremal case is also discussed separately.

In PR D87 (2013) no 12, 121503, we first show that stationary black holes satisfy an extremely simple quasilocal form of the first law, $\delta E = (\tilde{\kappa}/8\pi)\delta A$, where the (quasilocal) energy $E = A/(8\pi l)$ and (local) surface gravity $\tilde{\kappa} = 1/l$, with A is the horizon area and l is a proper length characterizing the distance to the horizon of a preferred family of quasilocal observers suitable for thermodynamical considerations. Our construction is extended to the more general framework of isolated horizons. The local surface gravity is universal. This has important implications for semiclassical considerations of black hole physics as well as for the fundamental quantum description arising in the context of loop quantum gravity.

In PRL 107 (2011) 241301, we made a statistical mechanical calculation of the thermodynamical properties of nonrotating isolated horizons. The introduction of Planck scale allows for the definition of a universal horizon temperature (independent of the mass of the black hole) and a well-defined notion of energy (as measured by suitable local observers) proportional to the horizon area in Planck units. The microcanonical and canonical ensembles associated with the system are introduced. Black hole entropy and other thermodynamical quantities can be consistently computed in both ensembles and results are in agreement with Hawkings semiclassical analysis for all values of the Immirzi parameter.

Most calculations of black hole entropy in loop quantum gravity indicate a term proportional to the area eigenvalue A with a correction involving the logarithm of A. This violates the additivity of entropy. In CQG 32 (2015) no 16, 165006, an entropy proportional to A, with a correction term involving the logarithm of the classical area k, which is consistent with the additivity of entropy, is derived in both U(1) and SU(2) formulations.

Earlier calculations of black hole entropy in loop quantum gravity led to a dominant term proportional to the area, but there was a correction involving the logarithm of the area, the ChernSimons level being assumed to be large. In PL B734 (2014) 49, we find that the calculations yield an entropy proportional to the area eigenvalue with no such correction if the ChernSimons level is finite, so that the area eigenvalue can be relatively large.

Future Research Plan:

(1) Investigate alternative theories of gravity. All other forces of nature, except gravity, can be described as gauge theories of compact gauge groups. Einstein's theory is also a gauge theory, but the gauge group is too large and non-compact. However, when all these forces including gravity are brought together in the framework of GR, the theory is invariant both under a compact gauge group $\mathbf{G}$, and diffeomorphism. Although GR does not unify these forces, it exhibits a curios fact about gravity that it is qualitatively different from other forces. If we hope for any unification of forces, this difference has to be overcome. An interesting attempt would be to modify Einstein's theory so that gravity is modified at short distances and behaves like a usual gauge theory at short distances (both attractive and repulsive) but at large distances it remains the same (to be consistent with all observations). Such models may be more susceptible to quantization because a gauge theory is controlled by a dimensionless coupling.

(2) Some low dimensional integrable systems and recently some higher dimensional integrable models show that non-perturbative Hilbert spaces of most field theories are very different from the Fock space. This is understandably so because of some general theorems found earlier in field theories that limits the use of Fock spaces for free systems only. Yet Fock description is very successful in describing almost-free field theories and in a large number of observations. However, the question remains whether these perturbative corrections converge to the exact Hilbert space calculations. This issue will be investigated further in the context of some exactly solvable field theories and attempts will be made to find out a way to calculate the Hilbert space beyond the perturbative Fock space.

8 Mathematical Physics

Present Research:

It is believed that quantum aspects of gravity play an important role at the Planck scale. General relativity and quantum mechanics together lead to a modification of the space-time which is described by noncommutative geometry. A particular type of noncommutativity described by the κ-Minkowski space-time appears in the description of a large class of black holes within this framework. It is interesting to ask if the Planck scale effects as encoded in the noncommutative geometry can have any signature on observable quantities. The gravitational waves arising from primordial black holes can carry signatures of the Planck scale physics and the recent discovery of gravitational waves provides a hope that such effects may be measurable in the future. In this context, the Planck scale corrections to the quasi-normal modes of certain black holes have been calculated and it has been shown that the quasi-normal frequencies indeed are modified due to the space-time noncommutativity. This gives a definite prediction of the Planck scale effects on gravitational waves which is in principle testable. The Bekenstein-Hawking entropy also undergoes a correction due to the same effect. In addition, it is believed that holography is an important feature of the physics at the Planck scale. The effect of noncommutativity in the boundary conformal field theories have also been analyzed in this context.

Various aspects of symmetries, anomalies, symmetry restorations through mixed states and the corresponding von Neumann entropies of physical systems have been analyzed. It has been shown that within a Hamiltonian approach to anomalies, parity and time reversal symmetries can be restored by introducing suitable mixed states. However, the expectation values of observables such as the Hamiltonian diverges in such mixed states. It has been shown that such divergent expectation values can be treated within a renormalization group framework, leading to a set of β-functions in the moduli space of the operators representing the observables. This leads to well defined expectation values of the Hamiltonian in a phase where the impure state restores the P and T symmetry. It is also shown that this RG procedure leads to a mass gap in the spectrum. It has also been shown that the scaling symmetry in conformal quantum mechanics can be broken due to the boundary conditions that follow from the requirement of a unitary time evolution of the Hamiltonian. However, the scaling symmetry can be restored by introducing a suitable mixed state, which is associated with a nonvanishing von Neumann entropy. This work provides a direct link between the restoration of a broken symmetry and von Neumann entropy.

A supercritical external Coulomb charge leads to strong field QED effects in graphene. It has been shown that the sample topology of the graphene sheet can affect the value of the supercritical charge. For certain conical topologies, the critical charge tends to zero and any external Coulomb charge would exhibit supercritical behaviour leading to strong electric field effects. This work provides to a direct experimental prediction of topological effects strong field QED features, which is measurable in the laboratory. In a related but different work, a Dirac type xp-model has been analyzed on a semi-infinite cylinder. The proposed model realizes the Berry-Keating conjecture on the Riemann zeros. This is related to gapped graphene with a supercritical Coulomb charge, which might provide a physical system for the study of the zeros of the Riemann Zeta function.

A non-periodic version of the Haldane-Shastry spin chain, whose ground state can be obtained from the chiral correlator of the $c = m - 1$ free boson boundary conformal field theory, has been studied. It has been shown that this model is integrable for a suitable choice of the chain sites depending on the roots of the Jacobi polynomial $P_N^{\beta-1,\beta'-1}$, where N is the number of sites and β, β' are two positive parameters. Furthermore, a complete description for the spectrum of this spin chain has been given in terms of Haldane's motifs and a classical vertex model. Polarized spin reversal operators along with their supersymmetric analogues have been used to construct new exactly solvable BC_N type of quantum integrable spin Calogero models and Polychronakos spin chains. It has been shown that an 'extended' boson-fermion duality relation is obeyed by the partition functions of such BC_N type of spin chains. Novel multivariate super Rogers-Szegö polynomials have been proposed and the corresponding generating functions have been constructed. A set of recursion relations for the partition functions of the BC_N type of Polychronakos spin chains, involving different numbers of lattice sites and internal degrees of freedom, have been derived by using such generating functions of super Rogers-Szegö polynomials. It has been shown that clusters of bound particles can be constructed for a quantum integrable derivative δ-function Bose gas for some special values of the coupling constant, which are connected with the Farey sequences in number theory.

Topological skyrmions as intricate spin textures were observed experimentally in 2d helimagnets. That such solitonic states appear as exact solutions in pure ferromagnets was shown by Belavin and Polyakov (BP). In (1) an innovative generalization of the BP solution has been proposed for anisotropic ferromagnets. The proposal is based on a geometric inequality that maps skyrmions to a new class of functions. The possibility of stabilizing such metastable states in helimagnets has also been discussed.

Integrable quantum field models are known to exist mostly in one space dimension. In (2) exploiting the use of multi-time in integrable systems and a Lax matrix of higher scaling order, a novel interacting quantum field model in quasi-two dimensions has been constructed. The Yang-Baxter integrability is proved for the model by finding a new kind of commutation rule for its basic fields. In spite of a close link with the quantum Landau-Lifshitz equation, the present model differs widely from it, in its content and in the results obtained. Using the algebraic Bethe ansatz the eigenvalue problem of this quantum field model has been solved exactly for all its higher conserved operators. The idea presented here should instigate the construction of a novel class of integrable field and lattice models and exploration of a new type of underlying algebras.

In (3) a novel notion of dual integrable hierarchies has been proposed, based on the notion of the nonlinear Schrödinger (NLS) hierarchy. For each integrable nonlinear evolution equation (NLEE) in the hierarchy, dual integrable structures exist by the fact that the zero-curvature representation of the NLEE can be realized by two Hamiltonian formulations stemming from two distinct choices of the configuration space, yielding two inequivalent Poisson structures on the corresponding phase space and two distinct Hamiltonians. This is fundamentally different from the standard bi-Hamiltonian or generally multi-time structure. The first formulation chooses purely space-dependent fields as configuration space; it yields the standard Poisson structure for NLS. The other one is new: it chooses purely time-dependent fields as configuration space and yields a different Poisson structure at each level of the hierarchy. The corresponding NLEE becomes a space evolution equation. The role of the Lagrangian formulation as a unifying framework for deriving both Poisson structures has been emphasized, using ideas from covariant field theory. One of the main result is to show that the two matrices of the Lax pair satisfy the same form of ultralocal Poisson algebra (up to a sign) characterized by an r-matrix structure, whereas traditionally only one of them is involved in the classical r-matrix method. We construct explicit dual hierarchies of Hamiltonians, and Lax representations of the triggered dynamics, from the monodromy matrices of either Lax matrix. An appealing procedure to build a multi-dimensional lattice of Lax pair through successive uses of the dual Poisson structures has been briefly introduced.

Nonperturbative exact solutions are available for several quantum integrable models in one space dimension. In (4) a novel nonlinear Schrödinger quantum field model has been constructed in quasi-two dimensions using an alternative to the Lax matrix approach and exploiting the hidden multi-space-time concept in integrable systems. An intriguing field commutator has been discovered, confirming the integrability of the model and yielding its exact Bethe ansatz solution with rich scattering and bound-state properties. The universality of the scheme is expected to cover diverse models, opening up a new direction in the field.

Future Research Plan:

The quantum gravity effects on conformally invariant systems can provide important insights into the holographic principle. Such effects are expected to show up both in black hole physics as well as in boundary conformal field theories, which are of great current interest. The conformal quantum mechanics, which is characterized by the $su(1,1)$ invariance, provides a simple framework to address many such questions. Taking noncommutativity as a paradigm for the Planck scale physics, it would be interesting to analyze its effects on the conformal quantum mechanics. The correlation functions of the conformal quantum mechanics are expected to pick up Planck scale corrections, which would be interesting within the context of holography. In addition, the analysis of unitarity and renormalization of such conformally invariant systems would also be carried out.

Another proposed area of research involves entanglement in quantum systems. There are many measures of entanglement, for example von Neumann entropy, which has been calculated for a very large class of physical equilibrium systems. It would be interesting to study the corresponding effects in the non-equilibrium scenario. In particular, how entanglement entropy changes as a function of time in a quenched system is of great current interest. The plan is to obtain analytical solutions of time dependent quantum systems and then to obtain the reduced density matrix and the entanglement entropy. This would require the system to be quenched, for which various experimental protocols exist. Recently there have been experiments using optical lattice to study entanglement entropy. The proposal is to study the time dependence of the von Neumann entropy in such systems which are experimentally realizable in the lab. The related topics such as the Loschmidt echo, survival probability and the orthogonality catastrophe would also be investigated.

Various properties of quantum integrable spin systems with long-range interaction and their supersymmetric generalizations, like the corresponding spectra, thermodynamical properties, correlation functions and entanglement entropy, will be studied. Related topics like Yangian quantum group symmetry, recursion relations for multivariable Rogers-Szegö type polynomials, Haldane's motifs, random matrix theory, classical vertex models and infinite matrix product states in conformal field theory will also be explored in connection with quantum integrable spin models with long-range interaction. Furthermore, various statistical properties associated with the spectra of such quantum integrable spin models, e.g., level density distribution and nearest neighbour spacing distribution, will be investigated by using analytical techniques and symbolic software package like Mathematica.