S.N. BOSE NATIONAL CENTRE FOR BASIC SCIENCES: A JOURNEY TOWARDS EXCELLENCE

(June, 1986 to May, 2021)

published on the occasion of

Golden Jubilee Celebration of Department of
Science & Technology, Government of India
May, 2021

S.N. BOSE NATIONAL CENTRE FOR BASIC SCIENCES : A JOURNEY TOWARDS EXCELLENCE

(June, 1986 to May, 2021)

published on the occasion of

Golden Jubilee Celebration of Department of Science & Technology, Government of India

S.N. Bose National Centre for Basic Sciences

An Autonomous Institute under Department of Science & Technology, Government of India

JD Block, Sector III, Salt Lake, Kolkata-700 106

प्रो. आशुतोष शर्मा
Prof. Ashutosh Sharma

सचिव
भारत सरकार
विज्ञान एवं प्रौद्योगिकी मंत्रालय
विज्ञान एवं प्रौद्योगिकी विभाग
Secretary
Government of India
Ministry of Science and Technology
Department of Science and Technology

13th April, 2021

Message

I am very happy to learn that S. N. Bose National Centre for Basic Sciences, Kolkata, has taken the lead in celebrating the Golden Jubilee Year of DST. The Centre was established as one of the autonomous institutes of DST in 1986 to honour the life and works of legendary physicist S. N. Bose, who is immortalized in the history of science by the coinages like bosons, Bose Statistics and Bose-Einstein Condensation. Over the last three and a half decades, the Scientists of the Centre have made their best efforts to pay homage to Bose's legacy through research and manpower training, and stands today as one of the premier national institutes of research in basic sciences. Based on the Nature Index ranking of quality of journal publications, the Centre is now among the top three DST institutes for the last few years.

It is noteworthy to mention here that the Centre has commemorated the Golden Jubilee celebration of DST in a befitting way throughout the year by organizing several seminars, science outreach programmes and has planned to publish the present Coffee Table book. This publication symbolizes the Centre's history of progress and legacy since its creation, and also embodies the current academic activities to inspire upcoming generations to be motivated to pursue a career in Science & Technology.

I wish the students and staffs of the S. N. Bose Centre the very best in their future endeavour for serving the nation through Research and Development activities.

(Ashutosh Sharma)

Technology Bhavan, New Mehrauli Road, New Delhi - 110016
Tel: 0091 11 26511439 / 26510068 | Fax: 00 91 11 26863847 | e-mail: dstsec@nic.in | website: www.dst.gov.in

Prof. B. N. Jagatap

Professor , Indian Institute of Technology, Bombay and
Chairman, Governing Body, S.N. Bose National Centre for Basic Sciences

At the outset, I congratulate the S.N. Bose National Centre for Basic Sciences (SNBNCBS) on bringing out this coffee table book that captures its history, evolution and achievements since its establishment in 1986.

Prof.Satyendranath Bose, well known for his momentous contribution to quantum mechanics and quantum statistics, was undoubtedly one of the most important scientists of the twentieth century. He was a teacher par excellence, who spent his career toiling away in university laboratories, class rooms and for his students.He was a home-grown scientist and his life reflected the true spirit of India.

Bearing the name of such a colossal genius is indeed a proud privilege for SNBNCBS. At the same time, it bestows on it a high level of responsibility and commitment. Prof. S.N. Bose had said, "We wanted to put scientific knowledge to use through technology for the benefit of the people or to contribute to science by intensive study." It is heartening to note that SNBNCBS is striving hard to fulfil the dream of Prof. S.N. Bose. Today it is an internationally recognized institute for frontline research in basic sciences and it is also engaged in the development of societal applications and technology transfers. Further, SNBNCBS is committed to science outreach programmes; the subject close to Prof. S.N. Bose's heart.

This coffee table book is not only a celebration of the success story of SNBNCBS, but it also marks the deep appreciation of the seamless efforts of the governing body, directors, faculty, administration and supporting staff, and students, all of the past and the present.

I sincerely believe that the perusal of the pages of this coffee table book will be an engaging experience for the readers and it will enlighten them on the role played by SNBNCBS in Indian science.

(B. N. Jagatap)

Prof. Samit K Ray

Director and Senior Professor

S.N. Bose National Centre for Basic Science

As a tribute to the legacy of legendary Indian scientist Satyendra Nath Bose, the founder of quantum statistics and father of bosons, the Department of Science & Technology, Govt. of India established the S. N. Bose National Centre for Basic Sciences on 13th June, 1986. With mandated objectives, the Centre undertakes cutting edge basic research, manpower training in advanced areas of research and networks globally to expand R&D based human capacity. Over the last three and a half decades the institute continued its commendable efforts to take challenges in the niche areas of Quantum Science & Technology, emerging areas of Theoretical Physics and Astrophysics, Computational Materials Science, Ultrafast Spectroscopy and Advanced Materials including soft, nano and biomaterials. In addition to the four departments for running the academic programme, the Centre has created thematic units of excellence on Nanoscience & Technology, Computational Materials Science and a Technical Research Centre (TRC) for undertaking translational research to contribute to make-in-India initiative of Govt. of India.

Professor Chanchal Kumar Majumdar joined as the Founder Director of the Centre on 1st June 1987 with the formal office of the Centre housed at a rented building (DB-17) in Salt Lake before the present campus came into full operation in August 1995 on a 15 acre lush green plot of land. In 1999, the Centre introduced a formal post-M.Sc. Ph.D Programme, which was followed up by starting an Integrated M.Sc.-Ph.D programme in 2001 in Physical Sciences. Though most of the research activities were initially focussed on theoretical and computational sciences, the scenario changed with the establishment of major experimental research facilities in 2005 onwards, and today the Centre stands as an institution of national importance with a balance of theory, computational physics and modern experimentation.

The Centre provides a strong platform to interact with global leaders in Science & Technology from academia, industry and government agencies. As per its original mandate, the Centre is also quite vibrant in science networking and contributes significantly to the DST's initiative on scientific social responsibility (SSR) by hosting a nodal Centre for Theoretical Physics Seminar Circuit (TPSC) and through a strong visitors and associates programme (VASP). It has been gratifying to see the recent growth of translational research activities through the DST sponsored Technical Research Centre (TRC) project, which has been a unique experience for the faculty members of a basic science institute to deliver not only industrial prototypes but also marketable products on low cost, non-invasive, healthcare solution for commercialization.

I am delighted that this coffee table book is being published on the occasion of Golden Jubilee Celebration of the Department of Science & Technology (1971-2021) by highlighting the growth of the Centre over the last three and a half decades, which also showcases some of the recent outstanding achievements by the researchers. This volume will be extremely helpful to assess the present strength of the Centre and to draw a blueprint of the vision for the next few decades. I am confident that the researchers of S. N. Bose Centre are not only equipped for the challenges in rapidly evolving S&T ecosystem of the country but also ready to contribute significantly in solving global scientific problems for making a signification contribution to the society.

(Samit K Ray)

JOURNEY

Prof. Chanchal Kumar Majundar (Second from right, holding the plan)
at the site - JD block, Salt Lake in 1989

BEGINS : NEW CAMPUS

Prof. C K Majumdar
during campus construction
in 1990

PREAMBLE

Established on the 13th June 1986, the Satyendra Nath Bose National Centre for Basic Sciences stepped into its 35th year in 2020. Following is a brief account of the journey of the Centre since its inception.

Professor Satyendra Nath Bose (1894-1974) was one of the foremost quantum physicists of the world. He is immortalized by his discovery of Bose Statistics in 1924. Subsequently, coinages like Bose-Einstein Condensation and Higgs boson highlight his contributions that remain relevant even to contemporary physics. Half of the fundamental particles of the universe - bosons - are named after him.

In order to pay tribute to the memory of this great son of the nation, the Govt. of India constituted a committee in 1982 headed by the Hon'ble Governor of West Bengal, and consisting of a few eminent scientists of the country, to study the feasibility of setting up a National Centre named after Professor Bose. The efforts reached fruition in 1986 when the Department of Science & Technology created this new Centre with an autonomous status. The Memorandum of Association of the Centre was registered under the Society Registration Act and a cluster of senior scientists and dignitaries signed as founder members of the Society. Prof. C K Majumdar was appointed Founder Director of the Centre in 1987. One of the Centre's major objectives, other than promoting excellence in research and manpower training, has been to provide a forum for intellectual interaction among scientists in India and abroad.

THE CAMPUS

The first office of the Centre was housed at the Indian Association for the Cultivation of Science. Subsequently, the Centre started functioning in rented houses in Salt Lake City of Kolkata with a growing number of faculty members and a fledgling library and computer centre.

In July 1986, the Government of West Bengal allotted a 15-acre plot in Salt Lake City for the own campus of the Centre. Construction activities started in 1990, and the campus came into full operation in August 1995, when an International Conference on Dynamics of Complex Systems was hosted. The infra-structure developments of the campus got further boosts at several stages since then with landscaping, and constructions of various buildings and research wings, as well as residential complexes. Now, as one enters the campus, a green and pleasant undulating landscape with the fully equipped Bhagirathi guest house provides a hearty welcome to the guest. To cater to the increased intake of doctoral and postdoctoral scholars along with a pool of visitors, new accommodation facilities such as Radhachura, Krishnachura, and Basundhara have come up in recent years.

Krishnachura Hostel

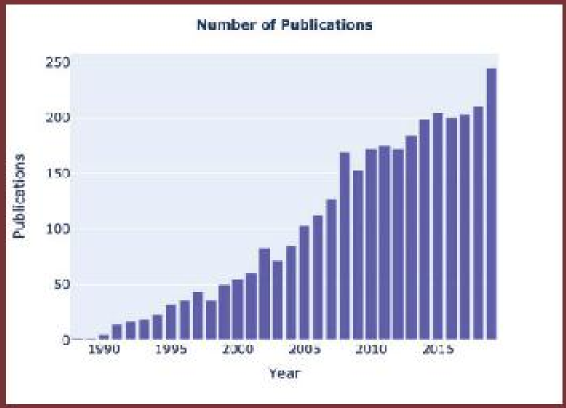
Prof. S Dattagupta with
Hon'ble Chief Minister in 2002

ACADEMIC ACTIVITIES OF THE CENTRE

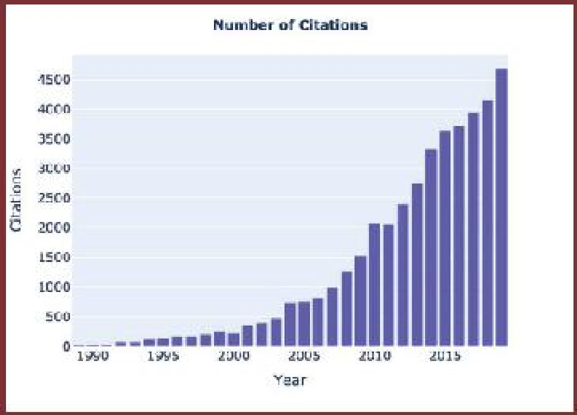
Since its establishment in 1986, S. N. Bose Centre undertakes cutting edge basic research in chosen areas of basic sciences including areas of application potentials, to train young persons in advanced areas to strengthen basic research and expand R&D based human capacity. Over the last decade the Centre has transformed itself from an institution with most activities in theoretical and computational areas, to an institution with a balance of theory, computer simulation, and modern experimentation. The Centre is a residential research institution with facilities like Hostels, Guest House, Library, Computer Centre, sophisticated research laboratories etc.

R&D PROFILE

At present, R&D activities in the Centre are carried out in four departments, viz., (i) Astrophysics and Cosmology, (ii) Chemical, Biological, and Macromolecular Sciences, (iii) Condensed Matter Physics & Material Sciences, and (iv) Theoretical Sciences. Among several current thrust directions, notable research progress has been achieved in the areas of Computational Materials Science, Quantum Science & Technology, Quantum Field Theory, Gravitational Physics, Statistical Physics and Theoretical & Observational Astronomy, Ultrafast Spectroscopy, Advanced Materials including nanomaterials, soft and biomaterials. The Centre has successfully completed several thematic units established by DST in the area of Nanoscience and Computational Materials Science with major extramural funding in these areas. Based on the research publications (263 publications with an average impact factor of 3.6) in the year 2019-20, the Centre is now among the top three DST institutes as per the Nature Index ranking based on the quality of publications. The Centre has undertaken a Technical Research Centre (TRC) project for transfer of research outputs for societal benefits and transferred seven technologies, with a strong relevance to the National Health Mission and Make in India programme of GOI. Scientists are involved in several National and Global research collaborations and have undertaken 27 Sponsored Research Projects with a total grant of INR 14.15 crores in the year 2019-20.



Number of publications per year



Number of citations per year
(Source: Web of Science as on 19th August, 2020)

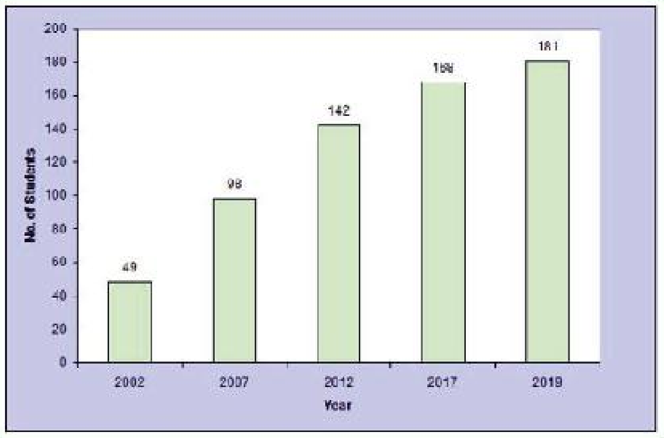
Areas of Current Research Focus:

- Classical and Quantum Field Theory, Gravitational Physics, Quantum Information and Foundations, Statistical Physics, Non-linear Dynamics and Mathematical Physics.
- Physical and Quantum Chemistry interfacing with Biological Molecules, Ionic Liquids and Energy Harvesting Materials
- Classical and Quantum Condensed Matter Physics, Advanced Materials Science problems including Nanomaterials and Nanodevices : Theory, Experiments and Simulation.
- Astrophysics and Cosmology: Investigation on black holes, dark matter, dark energy, star formation and observational astronomy, and astronomical instrumentation.

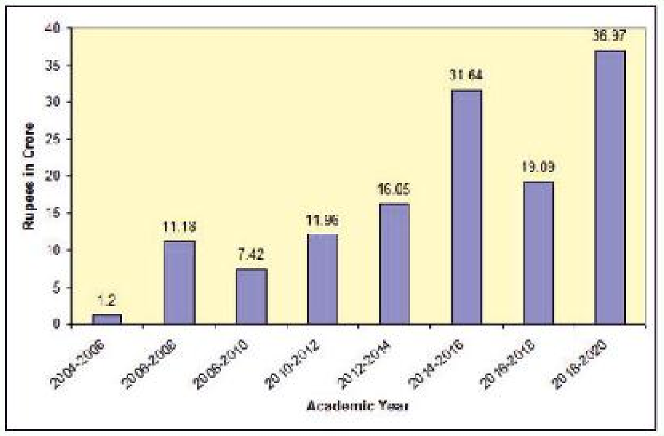
ACADEMIC PROGRAMMES

Human Resource Development is a key mandate of the Centre. The institute has thrived for excellence in research and training high quality scientific manpower through sustainable academic programs. With a current core strength of 31 regular faculty members, and with the support of Emeritus faculty, DST-Inspire Faculty etc. the Centre undertakes manpower training of around 160 doctoral students, 20 Integrated M.Sc.-Ph.D. students and 30 post-doctoral researchers. More than 20 specialized semester courses are offered each year, and additional training schools and workshops are organized for external students including summer projects for joint-academy funded scholars. In the year 2019-20, the Centre has contributed significantly to the creation of high quality manpower (an average of 0.97 Ph.D. completion per faculty per year). The Centre has completed supervision of 275 PhDs and about 30% of them so far have joined as faculty/researcher in leading universities and research institutes of India and abroad.

Electronic Class Room



Average yearly growth of number of students



Growth of sponsored project funds

ACADEMIC COLLABORATIONS

Strong academic collaborations exist with the Universities / Institutes at National and International levels for the award of M.Sc. / Ph.D degrees, exchange of students, joint extramural projects with Uppsala University, Sweden, Max Plank Institute, Stuttgart, Germany etc. A MOU with The World Academy of Sciences (TWAS) allows the visit of scholars from third world countries for Ph.D. and post-doctoral research studies.

Integrated M.Sc-Ph.D. Degrees are awarded by University of Calcutta through an existing MOU and students are registered for their Ph.D. in Jadavpur and Calcutta University. In 2020, the centre has started a joint Ph.D. programme with IISER, Kolkata

SNBNCBS and IISER - K, MOU
Signature for joint Ph.D. Program (2020)

TWAS-BOSE fellows at the Centre (2020)

MAJOR FACILITIES AND INFRASTRUCTURE

The Centre has created Thematic Unit of Excellence on Nanoscience with nanofabrication & a Class-1000 clean room facility, and Massively Parallel Cray supercomputing facility. The Centre is also equipped with research facilities like femtosecond time-resolved magneto-optical Kerr microscope, micro-focused Brillouin light scattering setup, cavity ring-down spectrometer, THz and ultrafast spectroscopy and several nanofabrication facilities like FIB, E-Beam lithography, dry etching and mask-less lithography etc. The Technical Cell and Technical Research Centre (TRC) with a large number of state-of the art characterization facilities cater to the research need of internal and external users, which are available for use through Indian Science, Technology and Engineering facilities Map (ISTEM) portal. The Centre possesses well equipped library and state-of-the-art computer centre.

Class 1000 clean room facility

Library


DELL

Bhagirathi Guest House

Vibrating sample magnetometer

Transmission electron microscope

X-ray diffractometer

Spectroscopy facilities

Nanolithography facility

CENTRAL COMPUTATIONAL RESOURCES FOR ITS RESEARCH PURSUIT :

The Computer Services Cell (CSC) of the S. N. Bose National Centre for Basic Sciences (SNBNCBS) is the leading Computing Centre having the state-of-the art computing facilities, catering to the ever-increasing demands of high performance computing for scientific and engineering research. The supercomputing facility at SNBNCBS is a symbiosis of computing, network, graphics, and visualization. The Centre housing state-of-the-art computing systems, with sophisticated software packages, is conceived of as a functionally distributed supercomputing environment, and connected by a powerful high- speed network.

S. N. Bose Centre's High Performance Computing facility being listed within top 50 supercomputers (CRAY XE6 & CRAY XC50) India based on the survey carried out by CDAC Bangalore. The cluster has a theoretical performance of 222.40 TF catering the computational need of the vibrant computational activity of the Centre.

Major Events & Milestones

- SNBNCBS is established (1986)
- SNBNCBS becomes national nodal centre for TPSC (1989)
- Bose Centenary Celebrations (1993)

  The Centre organizes an International conference "Bose and 20th Century Physics", and launches the centennial publication of two volumes entitled "S. N. Bose: The Man and His Work". During the year the Centre honours 300 hundred physics teachers all over the country. The Department of Post publishes a postal stamp commemorating Bose on 1st January 1994.
- Salt Lake Campus becomes functional (1995)
- Post MSc Teaching Program Started (1999)
- Integrated PhD Programme in Physical Sciences is launched (2001)
- Bust of S N Bose inaugurated by Hon'ble Chief Minister of West Bengal (2002)
- Extended Visitor Linkage Programme is launched (2010)
- Silver Jubilee Celebrations of S N Bose Centre (2011) with distinguished lectures, major international conferences and felicitation of Centre's staff
- Co-hosting of Centennial Celebration of Indian Science Congress (2013)
- Hosted DST Conclave (2017)
- Bose-125 Celebrations (2018)

  The Bose 125 celebration inaugurated virtually on 1st January 2018 by the Hon'ble Prime Minister, and the Hon'ble Minister of Science & Technology graces the occasion. Inauguration of a refurbished Bose Archive & Museum and an acclaimed documentary film on The Father of Boson: An Iconic Genius. Professor Wolfgang Ketterle visits the Centre to give Distinguished and Public Lectures. Several Bose-125 Distinguished Lectures by renowned scientists, and major International Conferences held throughout the year. The Centre collaborates with the Bangiya Bijnan Parishad to jointly organize more than hundred seminars in schools and colleges.
- Visit of Parliamentary Committee (2019)
- Opening of new Bose Archive and Museum (2020)

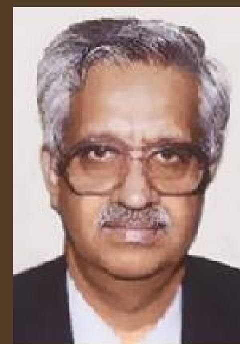
Centre started functioning in a rented premises at DB-17, Salt Lake

Founder Director Professor C K Majumdar (left) with Roger Penrose, Nobel laureate, 2020 (2nd from left) in an International Conference, 1994

THE GOVERNING BODY CHAIRMEN


Prof. V. Gowarikar


Prof. P. Rama Rao


Prof. V. S. Ramamurthy


Prof. T. Ramasami


Prof. Ashutosh Sharma


Prof. Srikumar Banerjee


Prof. B N Jagatap

THE DIRECTORS

Beginning from the first Director, Prof. C. K. Majumdar, to the present incumbent, Prof. S. K. Ray, the growth story of the Centre has been charted under the leaderships of

- Professor Chanchal Kumar Majumdar, Founder Director (1987-1999)
- Professor Sushanta Dattagupta (1999-2005)
- Professor Abhijit Mookerjee (2005-2006) - Officiating
- Professor Arup Kumar Raychaudhuri (2006-2014)
- Professor Sibaji Raha (2014-2015) - Additional Charge
- Professor Santanu Bhattacharya (2015-2016) - Additional Charge
- Professor Samit Kumar Ray (2016-2021)

Though their individual contributions may be too numerous to enlist here, they have provided crucial stimulus at various significant stages of development of the Centre, leaving characteristic imprints on its journey.


Prof. Chanchal Kumar Majumdar


Prof. Sushanta Dattagupta


Prof. Arup Kumar Raychaudhuri


Prof. Samit Kumar Ray

VISITORS' PROGRAMMES

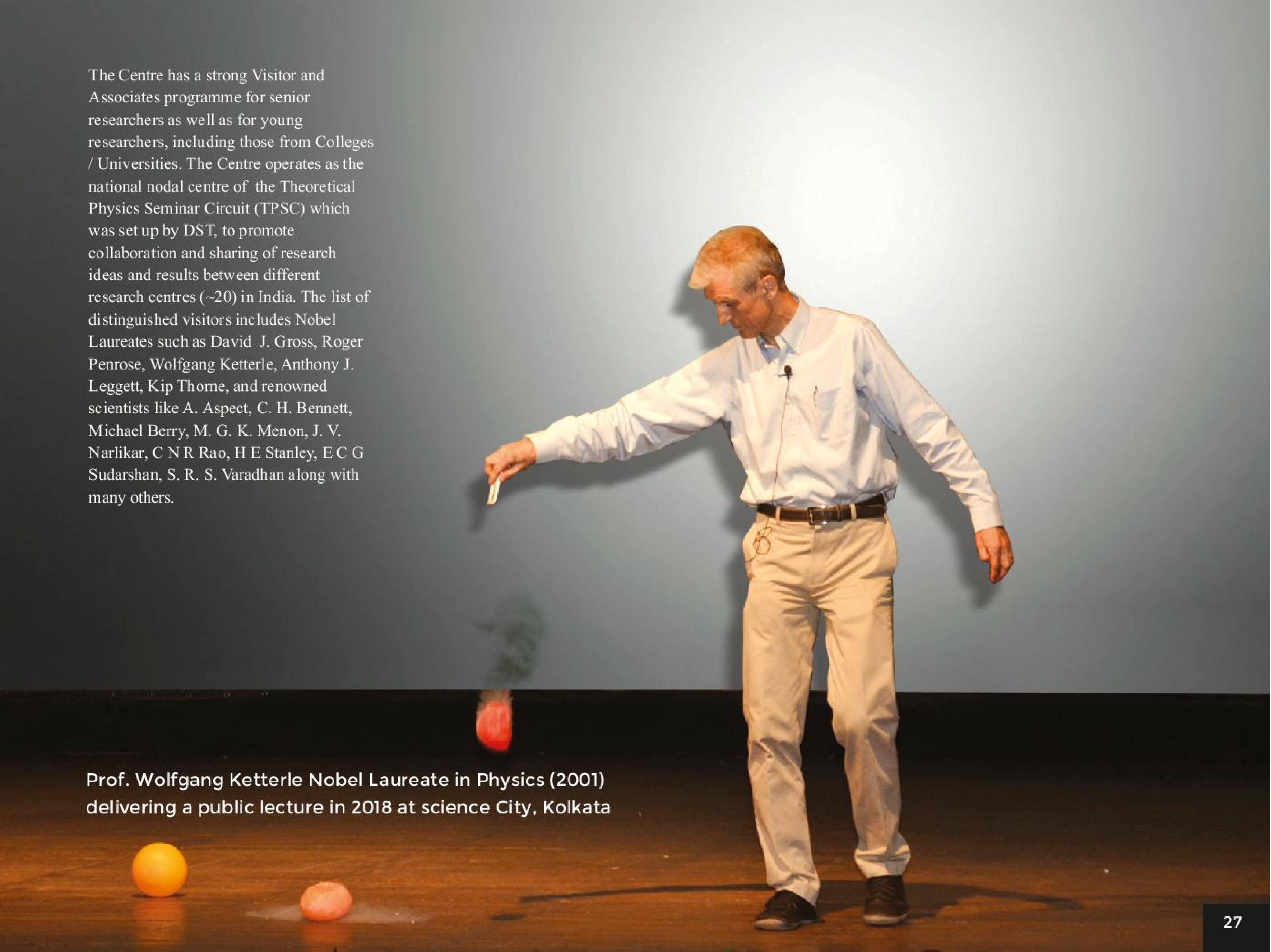
Prof. Alain Aspect and Prof. Anthony
J Leggett Nobel Laureate in Physics (2003) during Silver Jubilee
symposium (2011)

The Centre organized several international conferences and symposia to mark the major milestones such as Bose Centenary celebrations (1994), Silver Jubilee of the Centre (2011) and Bose 125 celebration (2018).

Professors - M. K. Dasgupta, E. C. G. Sudarshan, P. K. Kabir, C. K. Majumdar, P. Ghose, K. Nishijima, D. J. Gross, A. Aspect (left to right) at the Bose Centenary celebration (1994)

Prof. CNR Rao delivering S.N. Bose memorial lecture in 1999

The Centre has a strong Visitor and Associates programme for senior researchers as well as for young researchers, including those from Colleges / Universities. The Centre operates as the national nodal centre of the Theoretical Physics Seminar Circuit (TPSC) which was set up by DST, to promote collaboration and sharing of research ideas and results between different research centres (~20) in India. The list of distinguished visitors includes Nobel Laureates such as David J. Gross, Roger Penrose, Wolfgang Ketterle, Anthony J. Leggett, Kip Thorne, and renowned scientists like A. Aspect, C. H. Bennett, Michael Berry, M. G. K. Menon, J. V. Narlikar, C N R Rao, H E Stanley, E C G Sudarshan, S. R. S. Varadhan along with many others.



Prof. Wolfgang Ketterle Nobel Laureate in Physics (2001) delivering a public lecture in 2018 at science City, Kolkata

TWAS-Bose international conference on Bose Einstein Condensation (2018) on Celebration of 125th Birth anniversary of Bose (Bose-125)

Conference group picture during Silver Jubilee celebration (2011)

International Conference on Celebration of 125th Birth Anniversary of Bose (Bose 125)
Quantum Correlations (2018)

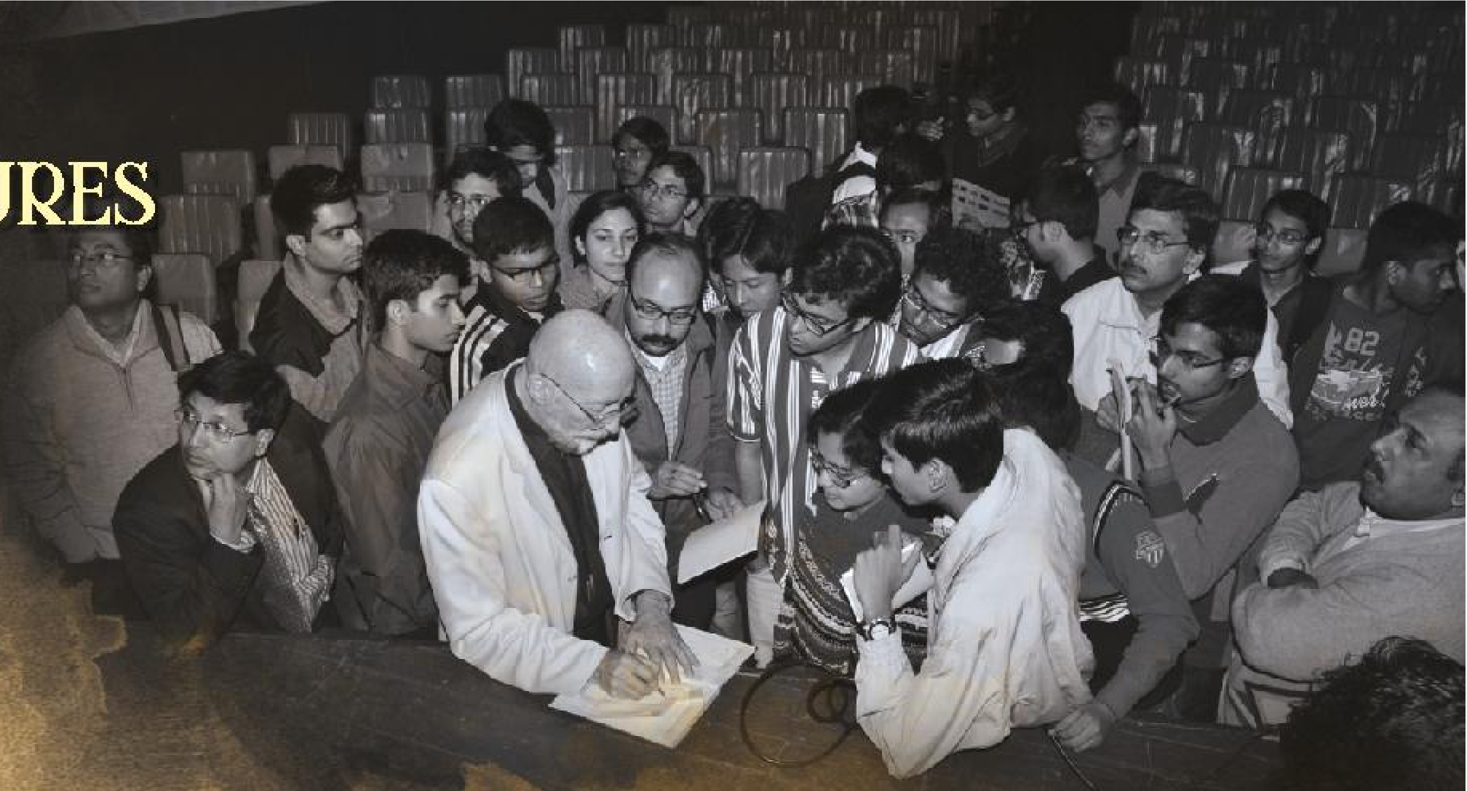
International Conference on Complex and Functional Material (2018)

International Conference on Nano Science and Technology (2020)

DST Conclave in Kolkata organized by the Centre (2017)

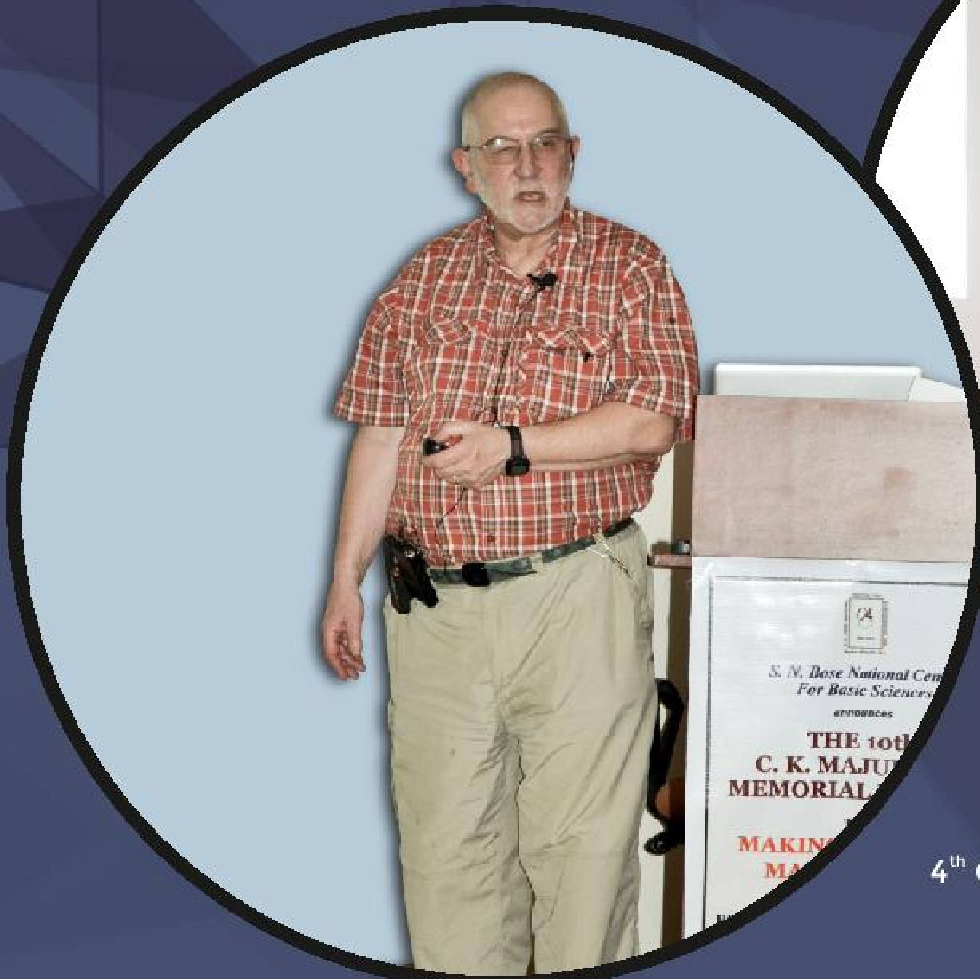
MEMORIAL LECTURES

The Centre holds four memorial lectures annually - named after S N Bose, C K Majumdar, S Chandrashekhar and G N Ramachandran.



Prof. Kip Thorne, Nobel Laureate (2017) interacting with students during the Silver Jubilee Lecture (2011)

Prof. A. K. Raychaudhuri felicitating Prof. Ashoke Sen during 18th S. N. Bose Memorial Lecture (2008)



Prof. Michael Berry delivering the
10th C. K. Majumdar Memorial Lecture (2012)

Prof. P. Balaram delivering
4th G. N. Ramachandran Memorial Lecture (2018)

2nd Chandrasekhar Memorial Lecture in 2011 by
Prof. Roger Penrose, Nobel Laureate in Physics (2020)

SCIENCE, SOCIETY, AND PUBLIC OUTREACH

The Centre follows vibrant social networking policy, and organizes various outreach activities. Lectures, workshops and training schools have been held in colleges and universities spread across the country. Some notable programmes have been held in remote areas such as Bhadrak College, Orissa, Gurucharan College, Assam, Nava Nalanda Mahavihara, Bihar, SKBU Purulia, VBU Hazaribagh, etc. Eminent novelists, artists, musicians, photographers, film-makers, and other public figures are invited from time to time for special lectures, performances and interactions with the Centre's community. Faculty members contribute regularly with popular science articles and talk shows in the print and electronic media. During Bose-125 celebrations in 2018, the Centre conducted more than 125 Science outreach programs in Schools, Colleges and Universities in 2018-19 across the nation to inspire the young generation in Science & Technology.

Hon'ble Prime Minister inaugurating the Bose-125 celebrations on 1st January, 2018

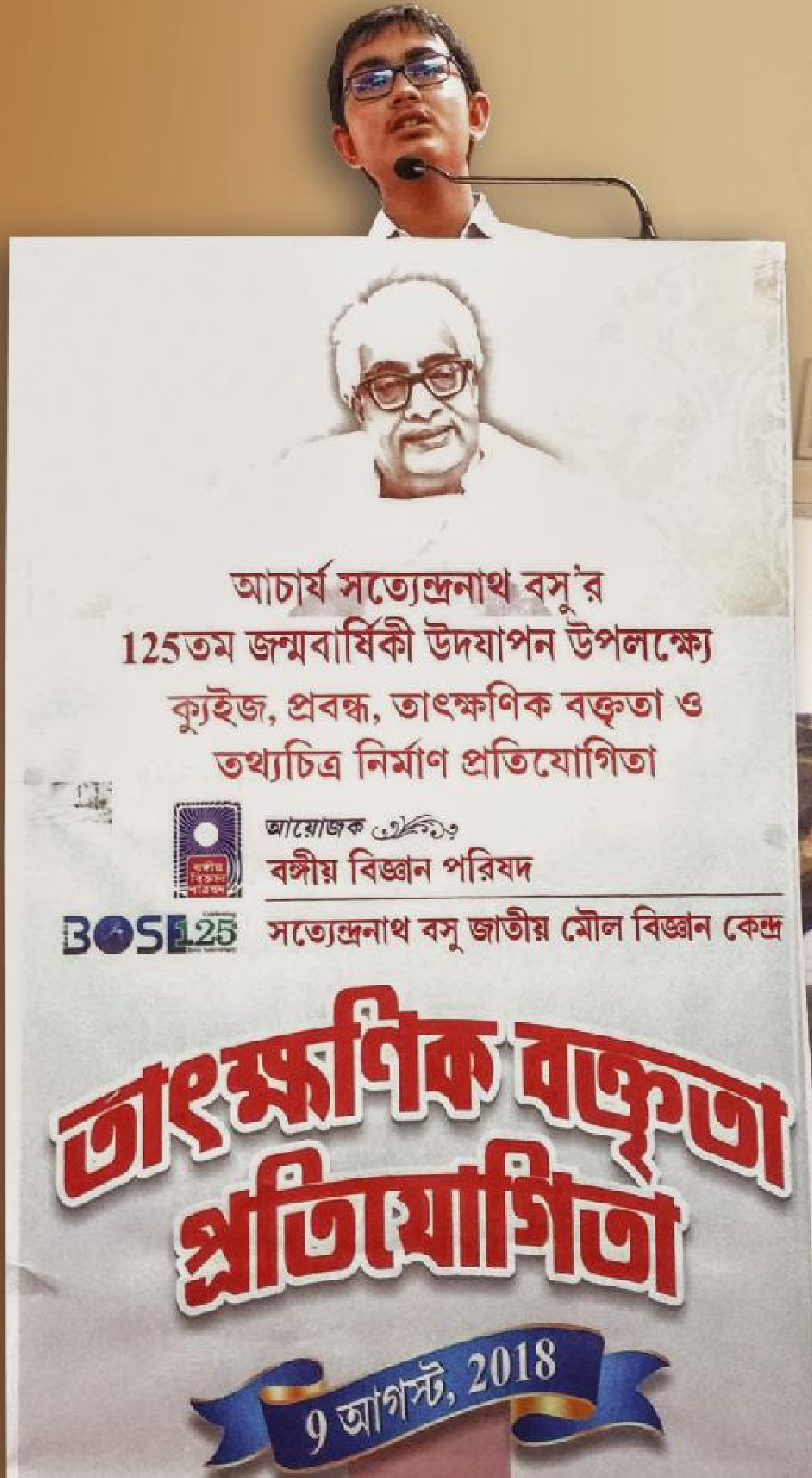
Release of the special cover on Bose's work during Bose-125 celebrations

Mobile exhibition van (from left to right) Dr. Harsh Vardhan (Hon'ble MoST), Prof. Ashutosh Sharma (Secretary DST), Dr. Srikumar Banerjee (Chairman GB), Prof. A. K. Sood (IISc), Prof. S. K. Ray (Director) and Prof. M. K. Sanyal (SINP)

Annual C. K. Majumdar Memorial Summer Workshop (2018)

Annual Vidyasagar-Bose Workshop (2020)

Bose-125 procession jointly with Bangiya Bijnan Parishad



Outreach activities during Bose-125 celebrations

North-East Students' Conclave (IISF 2019)

STUDENTS' LIFE ON CAMPUS

STUDENTS' ACTIVITIES

Students' marathon on 1st January, 2018 and cultural programme by students during Bose Fest 2019

Magazine published by Muktangan

Students' Life on Campus

The Centre has residential accommodations in Krishnachura and Radhachura for all M.Sc. and Ph.D. Students through the year the students organised numbers of cultural events and sports activities with Intra-Institute Table Tennis, Foot Ball, Cricket & Carrom Tournaments. The Literary Arts group of Muktangan also publishes the Cultural Magazine *"Sutra"*

BOSE ARCHIVE AND MUSEUM

Interior view of new Bose Archive and Museum

Bose Archive and Museum inaugurated by
Dr. Harsh Vardhan, Hon'ble Union Minister on 01.01.2018

Esraj of S. N. Bose in the Archive

SUCCESS STORIES : GLIMPSES

Important scientific achievements have been made by the Centre in several different branches of Theoretical, Experimental and Computational Physical Sciences, and Technology Development. Here we highlight some of our success stories in selected areas.

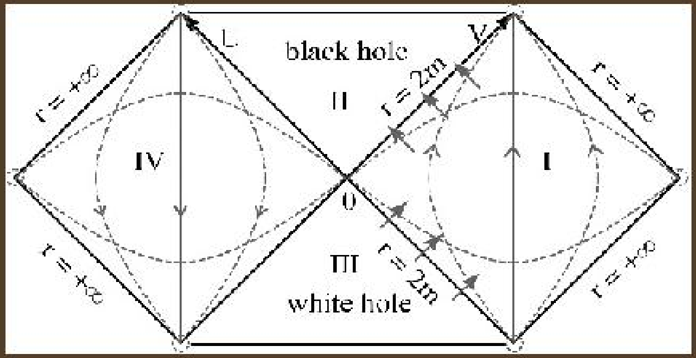
Quantum field theory, Gravity and Mathematical Physics

Theoretical physics, perhaps the oldest of the exact sciences, tries to satisfy the curiosities of the human mind of knowing the what and how by using mathematical tools to describe matter and its motion, and the forces affecting it from the smallest to the largest distance scales known to us. At very small scales below atomic sizes, physics has discovered the constituents of matter. Each atom consists of a heavy, positively charged nucleus made of particles called protons and neutrons, and light, negatively charged electrons bound to the nucleus by electric attraction. At even smaller scales physics recognises that protons and neutrons are also composite particles, made up of even smaller particles called quarks, which also make up many other particles known as mesons and baryons seen in high energy physics experiments such as the Large Hadron Collider. The forces which act between all these particles are called the fundamental interactions. Quantum field theory is the name collectively given to the tools of theoretical physics used for describing the properties, motion, and interactions of these particles.

At the other end of the scale we have stars and galaxies, whose interactions are gravitational and described to an astounding degree of accuracy by Einstein's General Theory of Relativity. The mathematics behind these theories and other branches of theoretical physics is a huge field of research and goes by the name of Mathematical Physics. From the Centre's inception our scientists have done pioneering, well acclaimed research in all of these fields.

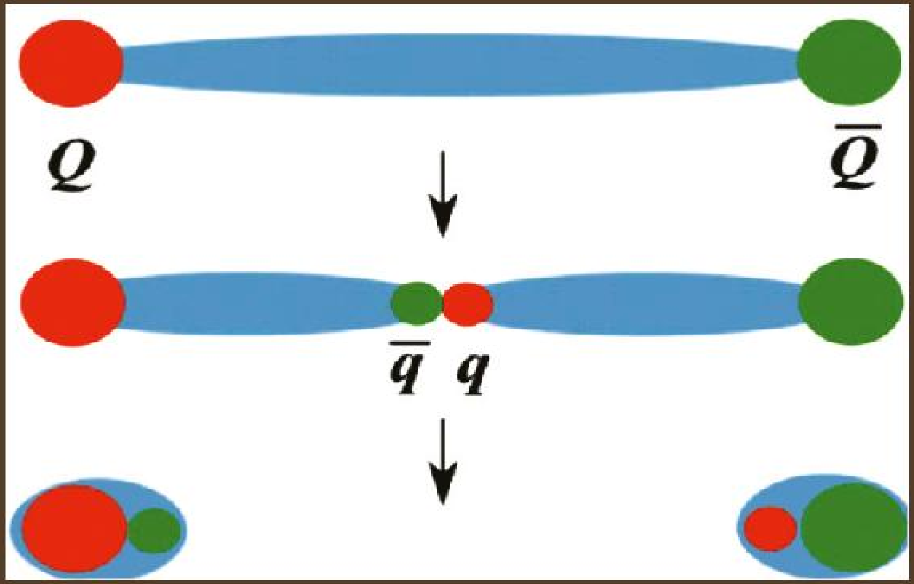
a) Gravitation: The most remarkable object predicted by Einstein's theory of gravitation is a black hole, which is an astronomical object whose gravitational pull is so strong that nothing escapes from it, not even light. It has long been a conjecture that an ideal black hole cannot have anything outside it - a statement known as the No Hair conjecture - a black hole has no hair. The scientists at the Centre have proven this mathematically for the case when there is a cosmological constant. The group here has also found a new method, based solely on covariant anomalies to compute the Hawking flux for a general class of black holes. A density matrix based approach was given for computing the Hawking black body spectrum in the tunneling approach.

References: Phys. Rev. Lett. **2007**, *99*, 201101.
Phys.Rev. D **2008**, *77*, 024018.

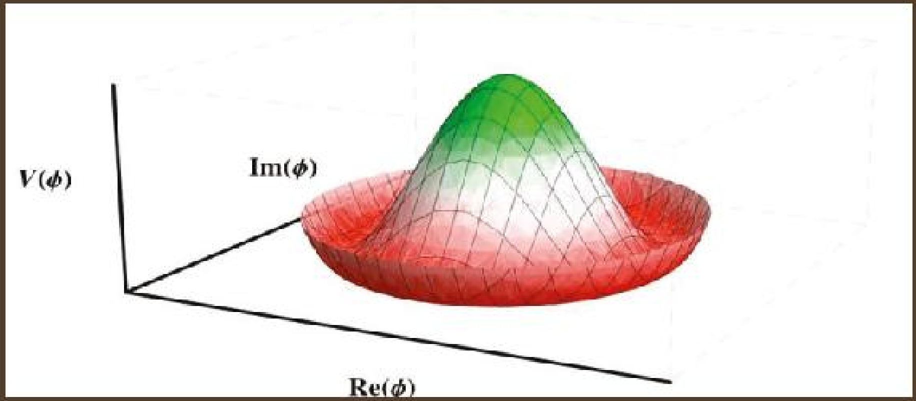


Penrose diagram of a Schwarzschild black hole

b) Quantum Field Theory: Quarks, the fundamental constituents of matter along with electrons, are never observed as free particles in Nature, they are always confined inside the protons, neutrons and other hadrons, all of which are composite particles made up of two or more quarks. Quark confinement is a quantum phenomenon which can be loosely described by a picture in which quarks are bound to one another by a microscopic string. Trying to pull quarks apart breaks the string and at the same time creates a pair of quarks stuck to the newly broken ends of the string. This way it is never possible to create a single free quark. How to create this structure in theories of quarks is still an unsolved problem. The group here has found a way to solve this problem in simpler theories, using a technique called duality, which also relates small distances to large distances and weakly interacting objects to strongly interacting ones, and thus has many applications even outside the problem of confinement. The group here is known for its extensive investigations of classical and

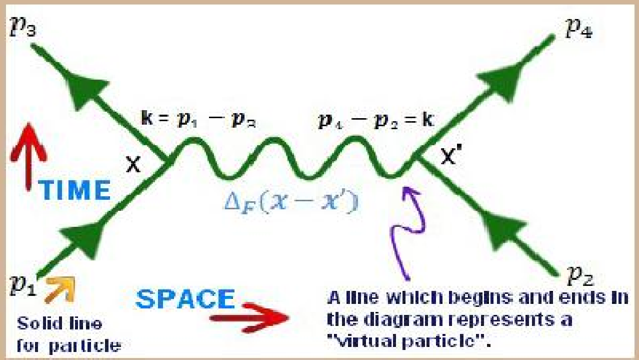


Breaking of string with creation of a quark-antiquark pair



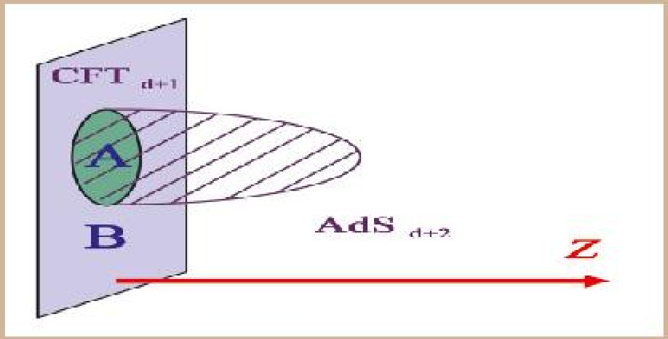
Higgs potential

quantum theories related by duality. These theories probe the origin of mass, and also has application in theories of superconductivity and fractional quantum Hall effect, and of course in models of quark confinement.



The Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity has been the most successful microscopic theory to describe weakly coupled superconductors with great accuracy. However, it has been realized that there materials like the high temperature cuprates where the understanding of the pairing mechanism remains incomplete. The failure of this theory to understand such strongly coupled systems invites new theoretical inputs. One such input comes from the so called AdS/CFT correspondence which provides remarkable theoretical insights in understanding the physics of high temperature superconductors. The group here has made significant contributions in investigation the effects of non-linear electrodynamics on holographic superconductors and have shown that the Born-Infeld coupling parameter indeed affects the formation of scalar hair.

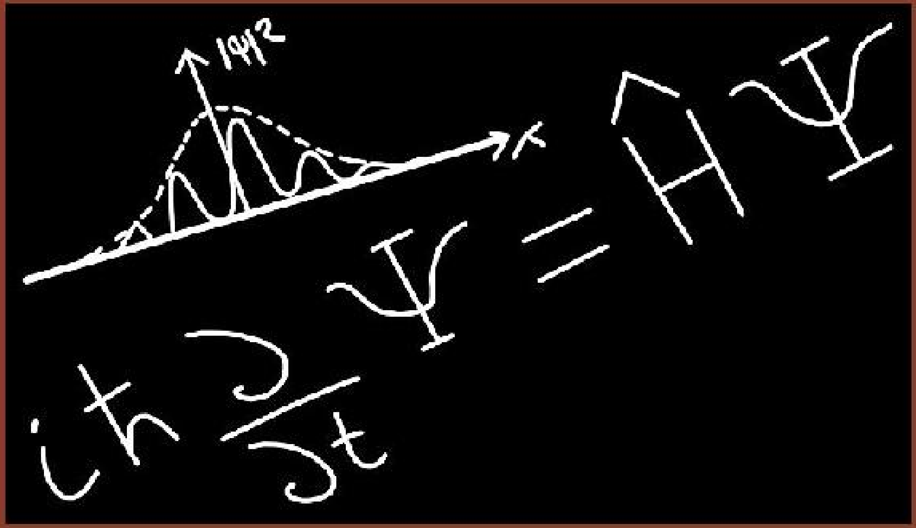
Reference : Jnl.High Energy Physics 05 (2012) 002.



Bulk-Boundary Correspondence

The group here has also done extensive research in the area of noncommutative quantum mechanics. Investigations carried out from this Centre have shown that a one-parameter family of physically equivalent noncommuting Hamiltonians in the Moyal plane can be constructed. It was eventually shown that one can have an approximate duality between an interactive commutative and non-interacting noncommutative theories. For singular magnetic fields, the filling fractions, computed at the incompressibility reproduced observed fractions for the fractional quantum Hall effect. Another remarkable result that was shown was that the Drinfeld twist required to restore Lorentz symmetry can also be responsible for the violation of Pauli's exclusion principle. This result can potentially have a deep impact in astrophysical compact objects such as white dwarfs and neutron stars. It was also realised that gravitational wave data can be used as an effective probe of noncommutative structure of space and the generalized uncertainty principle. It was demonstrated how spatial noncommutativity and the generalized uncertainty principle can modify the frequency of the resonant mass detectors of gravitational waves and also the corresponding probabilities of gravitational wave induced transitions that the phonon modes of the resonant mass detectors undergo.

Reference : Phys.Rev. D **2005**, *71*, 085005, *J. Phys. A: Math. Gen.* **2006**, *39*, 9557.



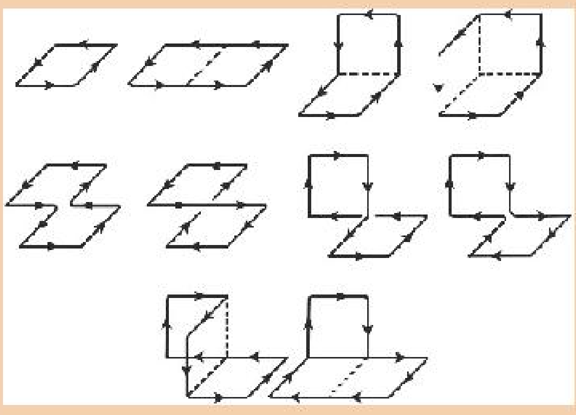
$$\left[\hat{x}^{\mu}, \hat{x}^{\nu}\right] = i\theta^{\mu\nu}$$

$$\Delta x^{\mu} \Delta x^{\nu} \geq \frac{1}{2}\left|\theta^{\mu\nu}\right|$$

Non-Commutative Quantum Mechanics

Wilson loops carrying non-abelian electric fuxes as the fundamental dynamical variables provide an alternative and interesting approach to study Yang Mills theories directly in terms of the gauge invariant loop variables. Their importance lies in understanding long distance non-perturbative physics, like color confinement. However, inspite of extensive work, a systematic transition from the standard formulation of gauge theories in terms of gauge potentials to a formulation in terms of Wilson loops was missing in the literature. The group in this Centre have used lattice regulated SU(N) Kogut-Susskind Hamiltonian formulation of gauge theories to address this issue. Using certain canonical transformations over the entire lattice, it was possible to transform all link flux operators to the loop flux operators. This way, the spin Hamiltonian, exactly equivalent to the Kogut-Susskind Hamiltonian, has been obtained.

Reference : Phys.Rev.D **2016**, *94*, 085029



Wilson loops used in making the Type-I gluonic operators

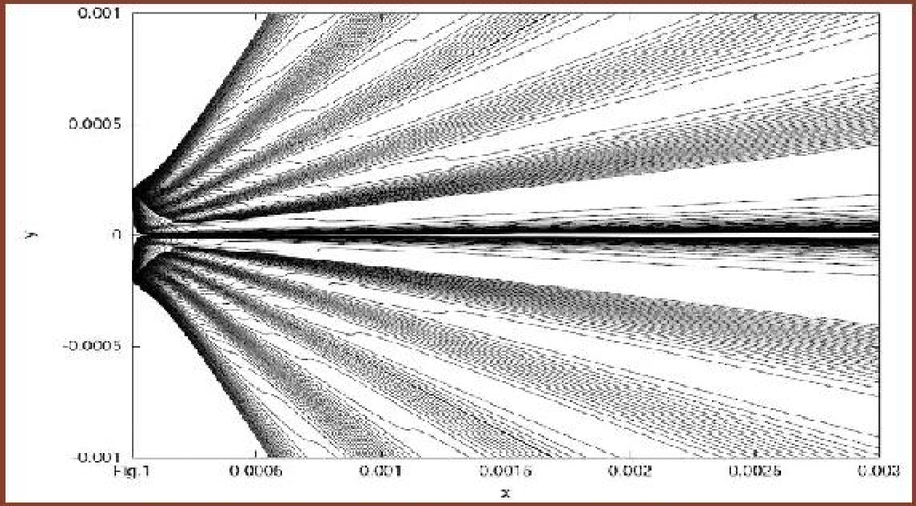
c) Mathematical Physics: Category theory is a branch of Mathematics where abstract mathematical structures and concepts are written in terms of diagrams containing points and arrows connecting them. The group here has found several mathematical results related to the application of Category theory in quantum field theories describing the formation and dynamics of strings with quarks or other charged particles attached to them.

Reference : J.Geom.Phys. **2015**, *98*, 128.

Quantum Information, Foundations & Quantum Optics

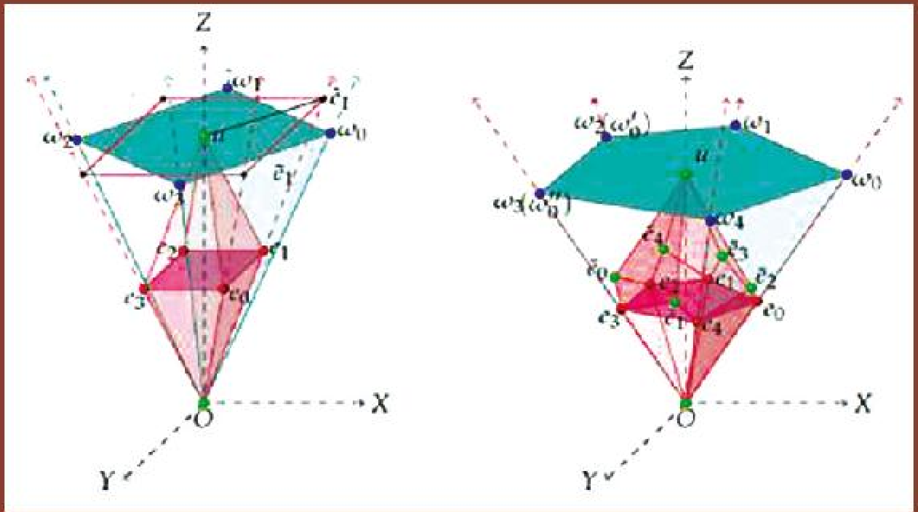
We are on the verge of a global quantum revolution. During the last two decades, certain key concepts have emerged leading to a deeper understanding of foundational issues in quantum physics. Experimental implementation of these ideas have led to a paradigm shift in the domain of quantum information and communication. Since its inception, SNBNCBS has been contributing to these developments in a vigorous manner, with a number of impactful breakthroughs in several topics of quantum information, foundations and quantum optics.

Early work by members of the Centre in the areas of foundations of quantum mechanics and quantum optics has paved the way for current activities in the area of quantum information. While work has mainly focussed on understanding and resolving several formal and applicational issues in quantum information science, the area of quantum optics is still pursued for its relevance in the realization of various quantum information processing protocols. Some of the notable early works on quantum foundations include wave-particle duality, photon trajectories in realist interpretations, and macroscopic limit of quantum mechanics[1].



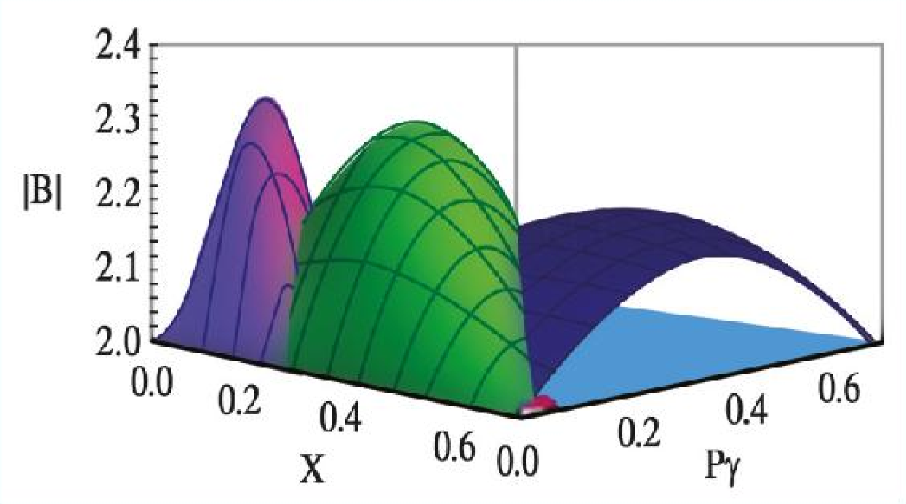
Bohmian Trajectories of Photons: two-slit interference

The ontological nature of the quantum wavefunction, the measurement problem, and approach to the macroscopic limit remain long-standing enigmas in quantum foundations. It has been proved that quantum violation of local realism persists in the macroscopic limit of large quantum numbers and large number of particles together. Violation of nonlocal realist inequalities free of geometrical constraints on measurement settings has been demonstrated. It has been shown how the principle of information symmetry can be used to constrain the state-space in any physical theory[2].



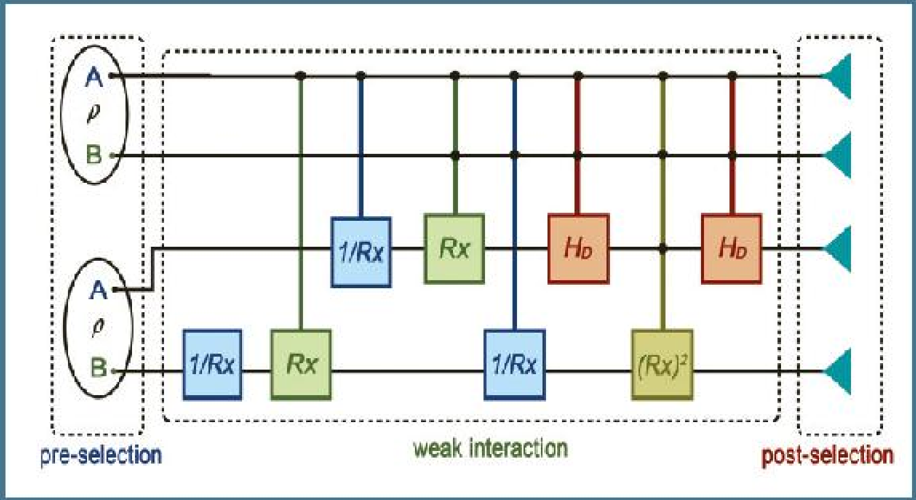
Squit and pentagon spaces in generalized probability theory

Subsequently, a large thrust of work shifted towards newly emerging areas of quantum information processing protocols. The existence of Hermitian operators acting as witness to detect entanglement useful for quantum teleportation, has been demonstrated, and examples of measureable linear witness operators have been provided. We are also the first to propose witness of states useful for entanglement creation, thus making a contribution to the long-standing problem of classifying absolutely separable states[3].



Violation of Bell inequalities in light beams with topological singularities

Novel linkages of quantum foundational principles have been developed with information theoretic resources, e.g., generalized uncertainty relation with purity and mixedness, fine-grained uncertainty relation with nonlocality, entropic uncertainty with quantum memory proving the existence of a universal lower bound of uncertainty achievable in actual experiments[4].



Universal detetction of entanglement in two-qubit states using weak measurements

Atom-photon interactions in cavity quantum electrodynamics, coherent states, and measures of non-Gaussianity and non-classicality have formed the backbone of investigations in the realm of quantum optics. Coherent states have been constucted for the commensurate anisotropic oscillator. A measure of non-Gaussianity of quantum optical states, as well as a measure of non-classicality based on Wehrl entropy have been proposed. Necessary and sufficient conditions have been obtained on the resource states for quantum teleportation of quantum optical states[5].

Quantum phenomena plays a role in band engineering that is important in the field of electronic circuits and performance of quantum devices. Quantum wave guide transport and conductance quantization have been studied in loop structures and modulated quantum channels. The generation of persistent currents in quantum rings have been investigated, and it has been shown that spontaneous symmetry breaking of the electronic ground state leads to interesting consequences[6].

References:

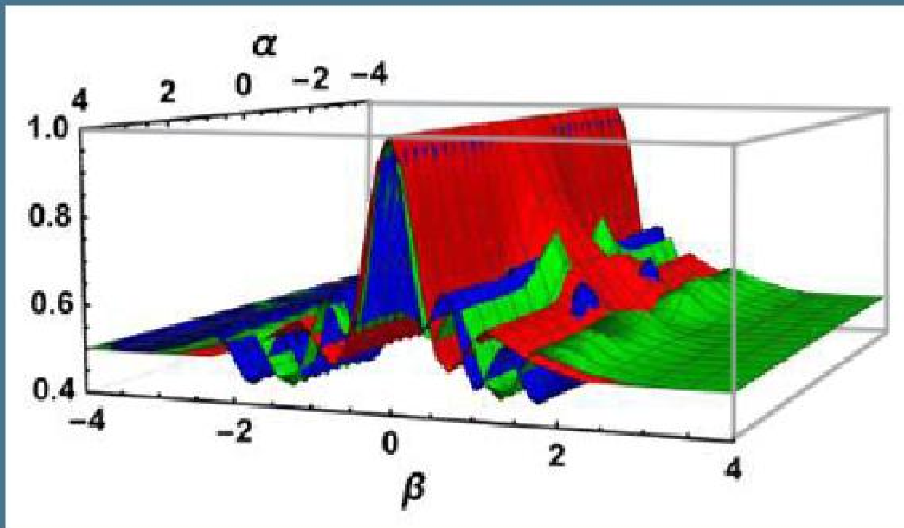
[1] *Phys.* Lett. A. 1991, 153, 403; Phys. Lett. A. **2001**, *290*, 205; *Phys. Rev. A*. **1995**, *52*, 4959.

[2] *Phys. Rev. A*. **2011**, *84*, 052115; *Phys. Rev. A*. **2019**, *100*, 060101®;

[3] *Phys. Rev. Lett.* **2011**, *107*, 270501; *Phys. Rev. A*. **2012**, *86*, 032315;

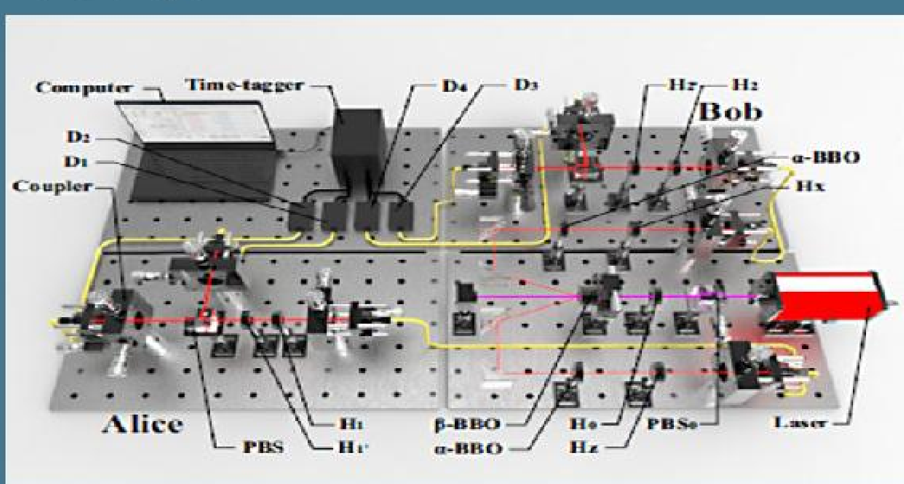
[4] *Phys. Rev. A*. **2012**, *85*, 024103; *Phys. Rev. A*. **2013**, *87*, 012105; *Phys. Rev. Lett.* **2013**, *110*, 020402.

[5] *Phys. Rev. A*. **2017**, *95*, 012330.



Einstein-Podolsky-Rosen steering of continuous variable states

Quantum nonlocality is a key resource for information processing tasks, as revealed by the violation of Bell-inequalities in light beams with topological singularities[7]. Environment-induced-decoherence is a major hindrance for quantum devices and protocols. Realistic environments with memory are modeled using non-Markovian dynamics. We have shown how non-Markovian evolutions can be detected using uncertainty relations, and proposed one of the first resource theories of non-Markovianity[8].



One-sided Device-Independent Self-Testing: experimental set-up

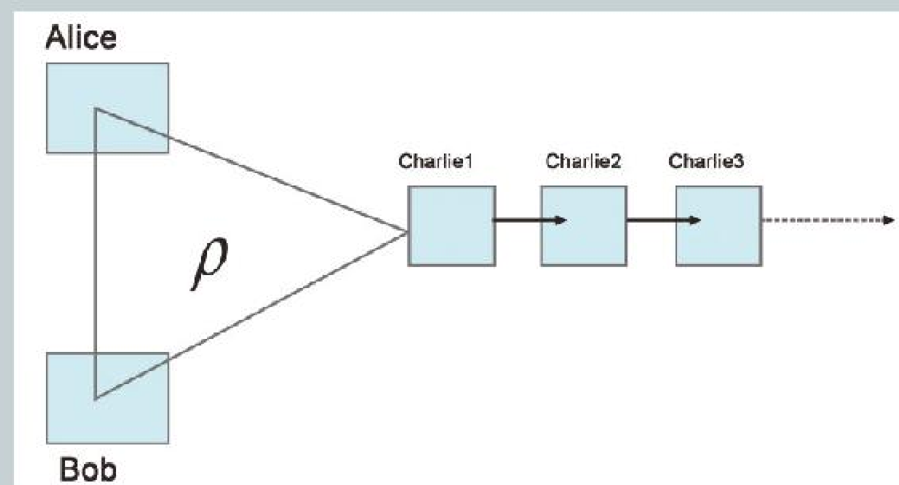
Einstein-Podolsky-Rosen (EPR) Steering proposed by Schrodinger in 1935, is now regarded to be of tremendous importance in security of quantum key generation protocols implemented in upcoming quantum technologies. We have addressed a number of key conceptual issues regarding EPR steering in the contexts of non-Gaussian states, fine-grained uncertainty for discrete, and continuous variable systems, sum-uncertainty relations, measures of steering, and tripartite steering. We are the first to propose and implement semi-device-independent self-testing of all pure two-qubit entangled states and corresponding measurement operations using quantum steering[9].

Reference:

[6] *Phys. Rev. B.* **1994**, *50*, 11629; *Phys. Rev. B.* **1998**, *58*, 10784; *Phys. Rev. B.* **2000**, *62*, 10668.

[7] Reference: *Phys. Rev. A.* **2013**, *88*, 013830; *J. Phys. A: Math. Theor.* **2020**, *53*, 175301; *J. Phys. A: Math. Theor.* **2021**, *54*, 035302.

Multiple use of a single copy of an entangled quantum state is a resource-efficient method for implementing practical information processing protocols. We are the first to provide an analytical proof of Bell-nonlocality sharing by at most two sequential observers on one wing of an entangled pair of qubits. This has been followed up by our subsequent demonstrations of sharing of steerability, sharing of the nonlocal advantage of quantum coherence, and sharing of tripartite entanglement[10].



Sequential detection of genuine triparite entanglement by multiple observers

Over the years, the group on Quantum Information, Foundations & Quantum Optics has produced more than 15 PhDs and trained about 10 post-doctoral fellows. A large number of national and international collaborations have been established. Theoretical ideas developed here have been experimentally tested in labs around the world such as Hamamatsu photonics, CQIQC, KAIST, USTC, PRL, CNRS[11]. Multiple externally funded projects have been implemented. We are actively engaging in the National Mission on Quantum Science & Technology with involvement in three sanctioned projects under the QuEST programme of DST.

[8] *Phys. Rev. A.* **2014**, *90*, 050305(R);
[9] *Phys. Rev. A.* **2016**, *94*, 042317; *Phys. Rev. A.* **2018**, *98*, 022311; *Phys. Rev. A.* **2020**, *101*, 020301(R).
[10] *Maths.* **2016**, *4*(3), 48; *Phys. Rev. A.* **2018**, *98*, 012305; *Phys. Rev. A.* **2020**, *101*, 042340.
[11] *Phys. Lett. A.* **1992**, *168*(1), 1-5; *Sci. Adv.* **2016**, *2*(2), e1501466; *Phys. Rev. A.* **2015**, *92*, 023822; *Phys. Rev. A.* **2016**, *93*, 053829.

Statistical physics including soft matter and chemical systems

The statistical physics group of the S. N. Bose National Centre for Basic Sciences (SNBNCBS) addresses a broad range of issues, concerning large- and meso-scale characterization of complex many-body systems in diverse natural setting. There are research activities where Statistical Mechanics tools are applied in variety of fields including soft matter and complex chemical systems where phenomena at large length and time scales are under investigation. Here are some glimpses into the wide range of problems carried out by various groups in SNBNCBS involving analytical, computational and experimental methods.

- Granular matter: Theoretical understanding of collective structural and transport properties of grains have been developed through studies of simple models of granular matter.

Reference: Phys. Rev. Lett. **1999**, *83*, 5170; *Phys. Rev. Lett.* **1999**, *83*, 304; *Phys. Rev. Lett.* **2005**, *94*, 088002)

- Network theory: The structural characterization of networks (e.g., the Internet or the international trade network) has been achieved; These works help one to understand the networks' flow distribution properties and thus to make the networks more efficient.

Reference: Phys. Rev. E. **2003**, *67*, 036106; The International Trade Network. In: *Econophysics of Markets and Business Networks* (pp. 139-147).

- Critical phenomena and the renormalization group: The effects of critical fluctuations on sound propagation in a fluid near critical point and the critical-phenomena related renormalization group technique to tackle nonlinear dynamics problems have been explored.

Reference: J. Phys. Chem. B. **2013**, *117*, 3790-3797; *EPL* **2010**, *91*, 60004; *Eur. Phys. J. D.* **2011**, *61*, 443-448

- Structural properties of solids: A dynamical framework is provided to understand a ubiquitous class of microstructures in solids - martensites and ferrites.

Reference: Phys. Rev. Lett. **2003**, *91*, 045502; *Phys. Rev. Lett.* **2004**, *93*, 115702

- Diamagnetism and dissipation in quantum mechanics: Landau diamagnetism and quantum dissipation have been explored to demonstrate how dissipation gives rise to transition from a coherent orbital motion of a charged particle in a magnetic field to an incoherent thermal motion.

Reference: J. Phys.: Condens. Matter **2006**, *18*, 10029

- Signalling noise and the chemotactic performance of E. coli: The chemotactic performance of a cell like E. coli is measured in terms of how fast the cell is able to drift towards the nutrient-rich region, or how effectively the cell is able to localize in that region in the long-time limit; Indeed the best chemotactic performance is obtained at an optimum strength of the methylation noise!

Reference: Phys. Rev. E. **2021**, *103*, L030401

- Driven matter: A simple characterization of driven systems, which are ubiquitous in nature and arguably the closest counterpart to those in equilibrium, is highly desirable. An intriguing relationship between fluctuation and transport is found in a broad class of driven passive and active matter;

Reference: Phys. Rev. Lett. **2014**, *112*, 030601; *Phys. Rev. E.* **2020**, *101*, 052611

- Model Calculations on Multiscale dynamics in open Chemical and Biological Systems: Self-sustained chemical oscillations are regularly observed in biological world. These phenomena have been studied by multiscale perturbation analysis for systematic design of oscillators with desired number of limit cycles.

Reference: Physica D: Nonlinear Phenomena **2021**, *416*, 132793; *J. Math. Chem.* **2018**, *57*, 750-768; *J. Math. Chem.* **2017**, *55*, 887-910

- Coarse-grained simulations on soft matter system: Extensive Brownian Dynamics simulations studies have been undertaken to understand dynamics of colloidal systems. Under electric field, similar charges form lanes and a transverse cross section forms patterns with particles having slower diffusivity. Well-defined correlation length characterizes the patterns.

Reference: Phys. Chem. Chem. Phys. **2020**, *22*, 17731

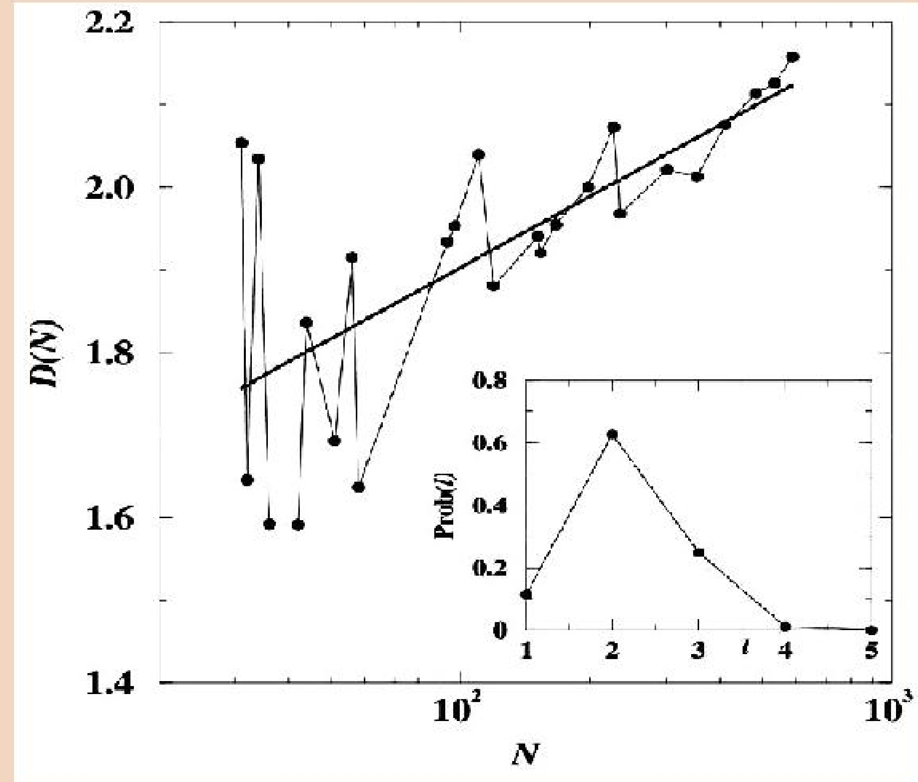
- Large Scale simulations on bio-molecules: Large scale computations are performed to understand the connection between structure, interaction, dynamics and function of bio-molecular systems. Changes in one part of a protein affect motions of distal part which is known as dynamic allostery. All-atom simulations have been performed to show that proteins may have evolved a unifying universal response system involving hydrogen bonded network to different types of external perturbations.

Reference: J. Phys. Chem. Lett. **2020**, *11*, 9026

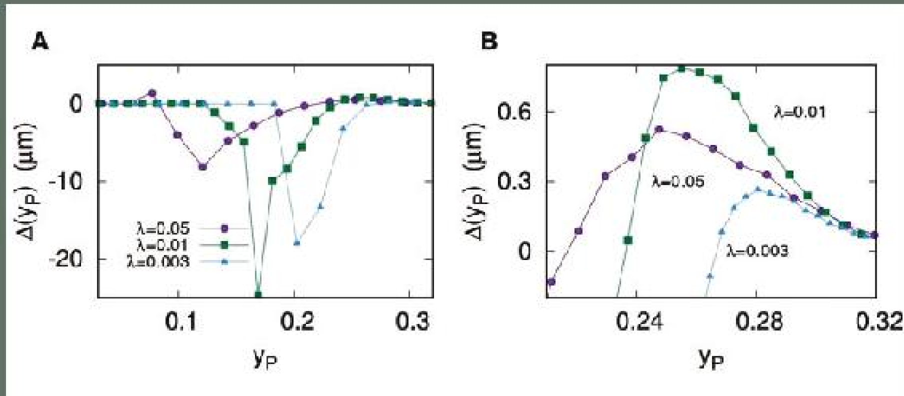
- Spectroscopic measurement on Complex Chemical System-Deep Eutectic solvents. Often a mixture melts at a temperature much lower than the melting temperature of the components. This depression of the melting point is a source for preparation of a new class of solvents known as deep eutectic solvents, and a manifest of colligative property often read in Physical Chemistry. Spectroscopic studies of deep eutectic solvents have taken center stage of our research in the last several years to establish their dynamical properties distinct from normal fluids.

References: *J. Phys. Chem. B* **2019**, *123*, 9378-9387; J. Mol. Liqds. **2020**, *303*, 112451(1-11)

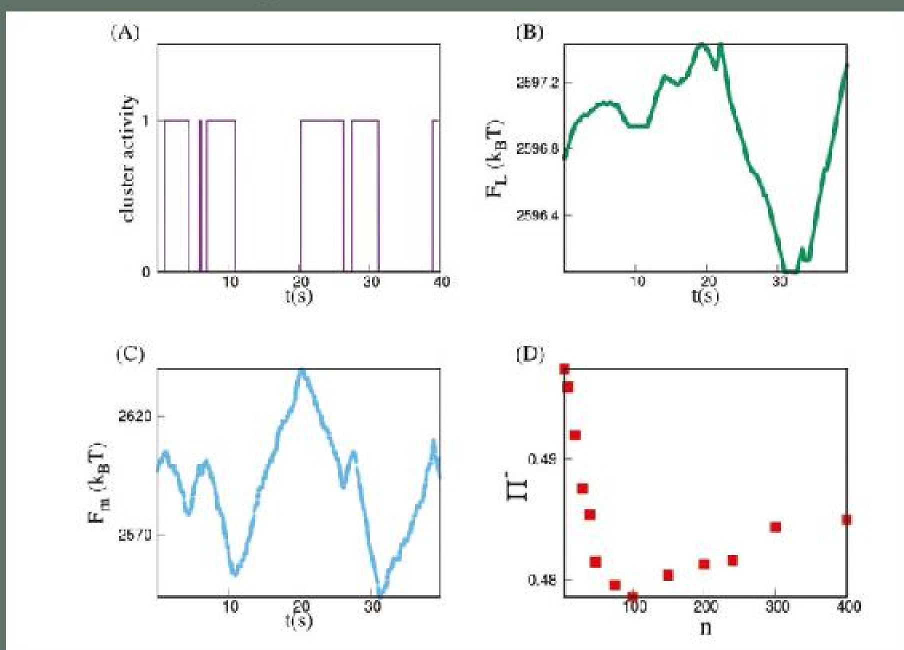
- Scanning probe methods for biomolecular interface: Experimental techniques to probe bio-molecular phenomena are one major area of research. We have developed a potential colon cancer biomarker, Hyaluronan, using Atomic Force Microscope (JPCL 2020).



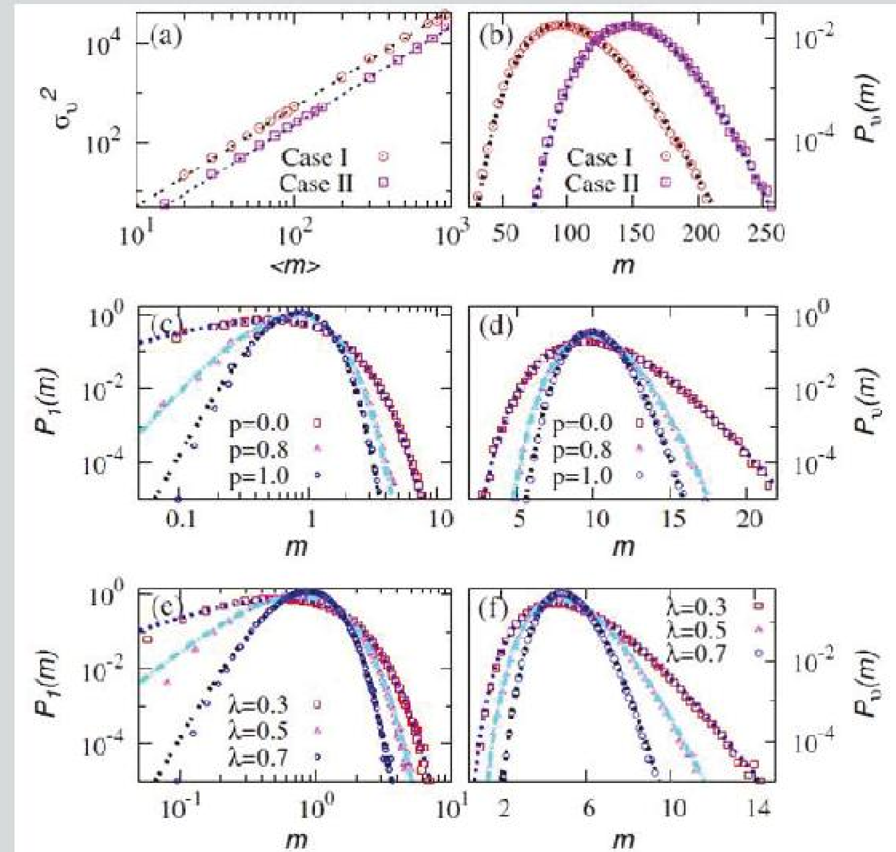
The plot represents the mean path length D(N) between a pair of nodes on the graph representing the Indian Railway Network (IRN). The most important subset of IRN with N = 587 stations and 579 trains have been considered. The plot exhibits the validity of D(N) = A + B log(N) type relation that signifies that the IRN is a small-world network.



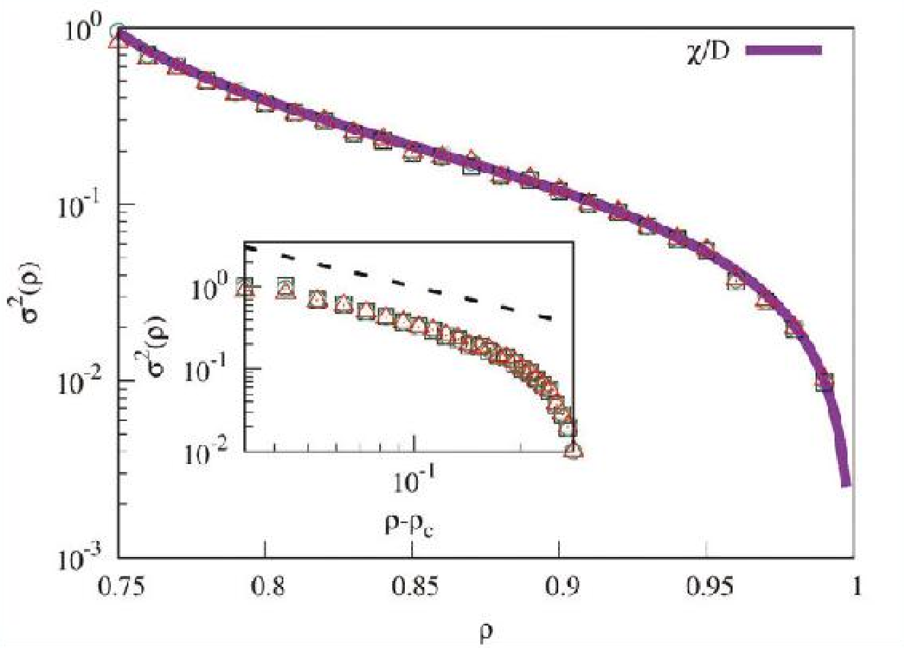
Net displacement during a run for different noise strengths. The quantity y_P denotes the fraction of phosphorylated CheY molecules, at the start of the run, and the quantity $\Delta(y_P)$ denotes the average displacement in that run. While the position of the peak shifts towards left as the noise increases, the height of the peak clearly shows non-monotonic behaviour with the noise: the highest peak is observed close to the optimal noise $\lambda*$.



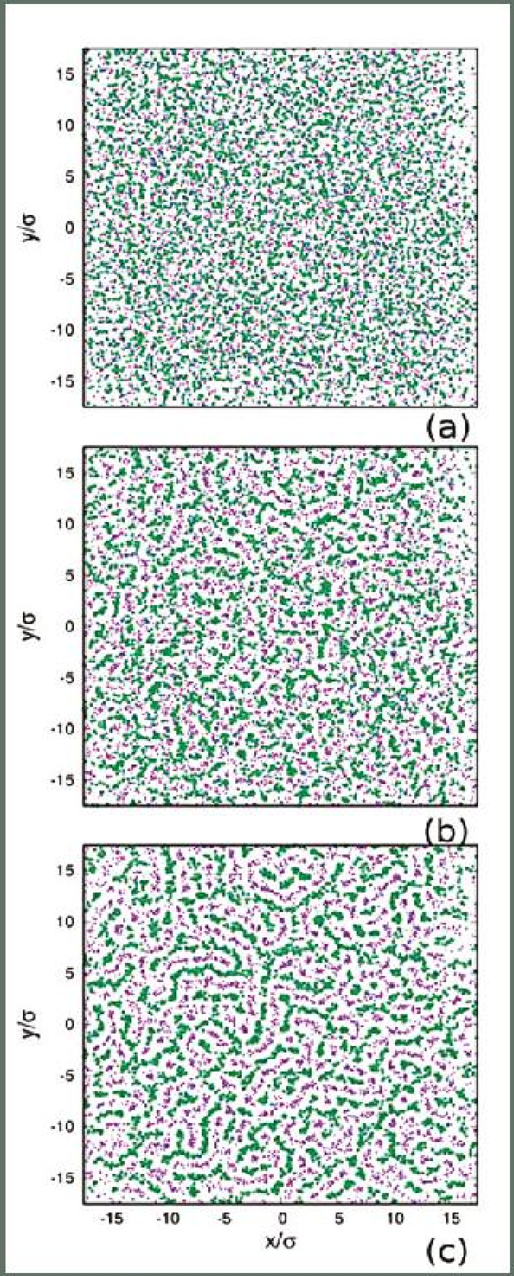
Typical time series of activity along with methylation component and ligand component of free energy of a receptor cluster of size n=200. (a) A few transitions of activity state of the cluster. (b) Simultaneous variation of free energy (in unit of k_BT, where k_B is the Boltzmann constant and T is the temperature) due to ligand binding, which directly captures the run-tumble trajectory of the cell. (c) Variation of the methylation free energy (in unit of k_BT) of the cluster, which is seen to roughly follow the activity transitions. The scale of the variation of the ligand binding energy is negligible compared to that of the methylation for the present value of n. (d) Probability Π - that, in a time interval t=40s, the net displacement of the cell is negative, shows a minimum, and then increases for larger n.



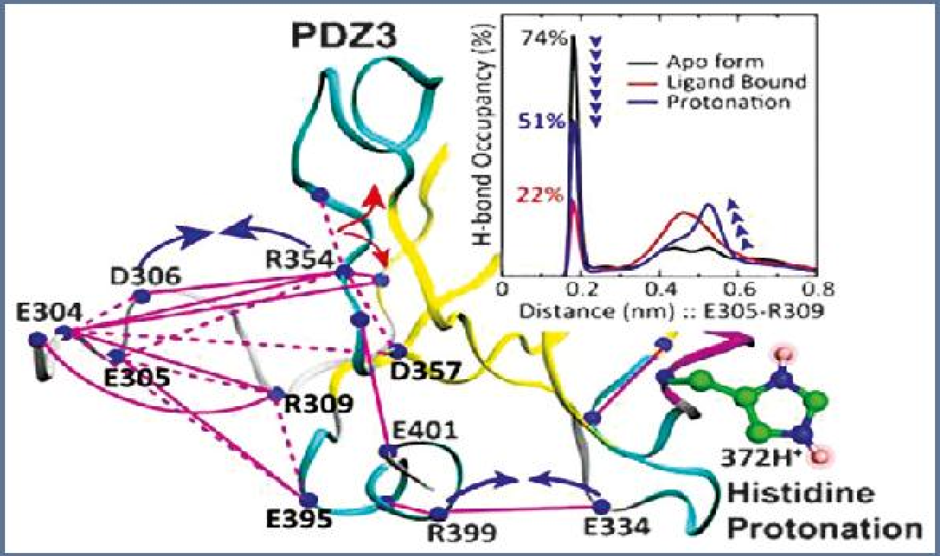
A broad class of out-of-equilibrium (driven) conserved-mass transport process, which are ubiquitous in nature and happen through fragmentation, diffusion and coalescence, are studied. An interesting feature in many of these transport processes is that the probability distributions of mass in a sub-domain are described by gamma-like distributions. However an intriguing question why the gamma-like distributions arise in different contexts remained unanswered and was explained by us. We provide conditions under which the gamma-like mass distributions can arise in the conserved-mass transport processes. (a) The variance of subsystem mass is plotted as a function of average subsystem mass <m>. (b) - (f) Single-site and subsystem mass distributions $P_1(m)$ and $P_u(m)$, respectively, are plotted as a function of respective mass m for various parameter values of several classes of conserved-mass transport processes. In all cases [(b) - (f)], gamma-like mass distributions are observed. Points are Monte Carlo simulations. Lines are obtained from an additivity theory, which captures the simulations quite well.



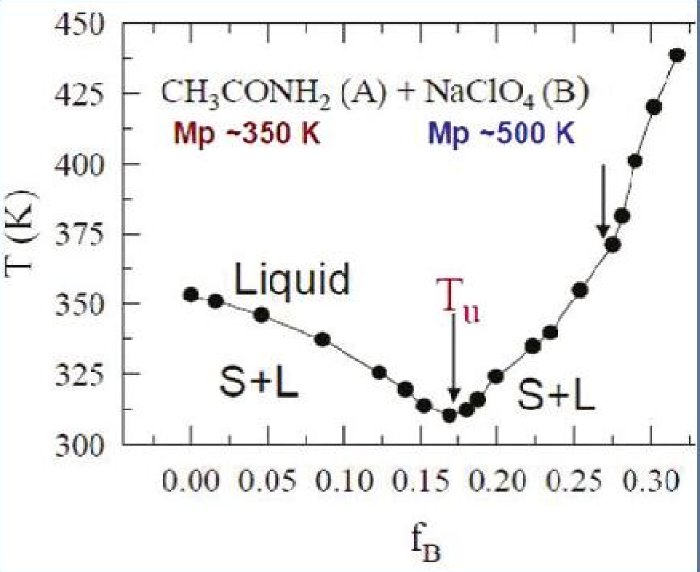
A model system of interacting self-propelled particles with long-ranged hopping have been studied. Suitably scaled variance of subsystem (coarse-grained) particle number, obtained from simulations (points), and the ratio $\chi(\rho)/(D)(\rho)$ of the two density-dependent transport coefficients - the conductivity $\chi(\rho)$ and the bulk-diffusion coefficient $D(\rho)$, obtained analytically from a hydrodynamic theory (lines), are plotted as a function of number density ρ. Notably, the number fluctuation is found to be related to the ratio of the two transport coefficients through an Einstein relation $\sigma^2(\rho)=\chi(\rho)/D(\rho)$. The model system here exhibits a non-equilibrium condensation transition below a critical density, where the conductivity and the number fluctuation diverge, thus providing a dynamical mechanism to the "giant" number fluctuation, which have been observed in various active matter systems in the past. **Inset**: The scaled number fluctuation is plotted as a function of density difference ($\rho-\rho_c$), where the guiding line (black dashed) shows a simple-pole singularity in the number fluctuation $\sigma^2(\rho)\sim 1/(\rho-\rho_c)$.



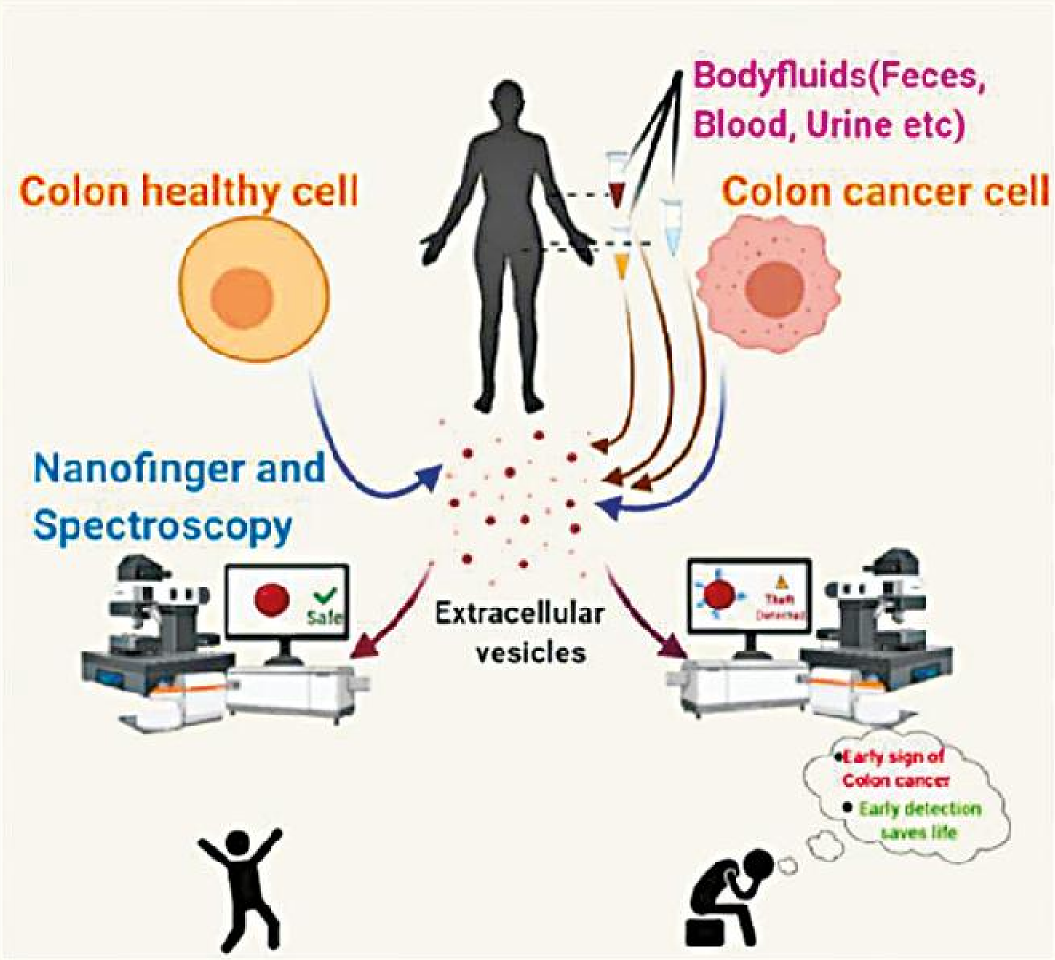
Organization of slower particles as with time increasing from top to bottom (a) to (c). The colours are for two opposite charges.



PDZ domain protein demonstrates a classic example of dynamic allostery, where distal dynamics of side-chains gets modulated on ligand binding without discernible structural changes



Addition of an electrolyte, sodium perchlorate (NaClO4) to an organic compound, acetamide (CH3CONH2) can bring down the melting temperature near to room temperature.

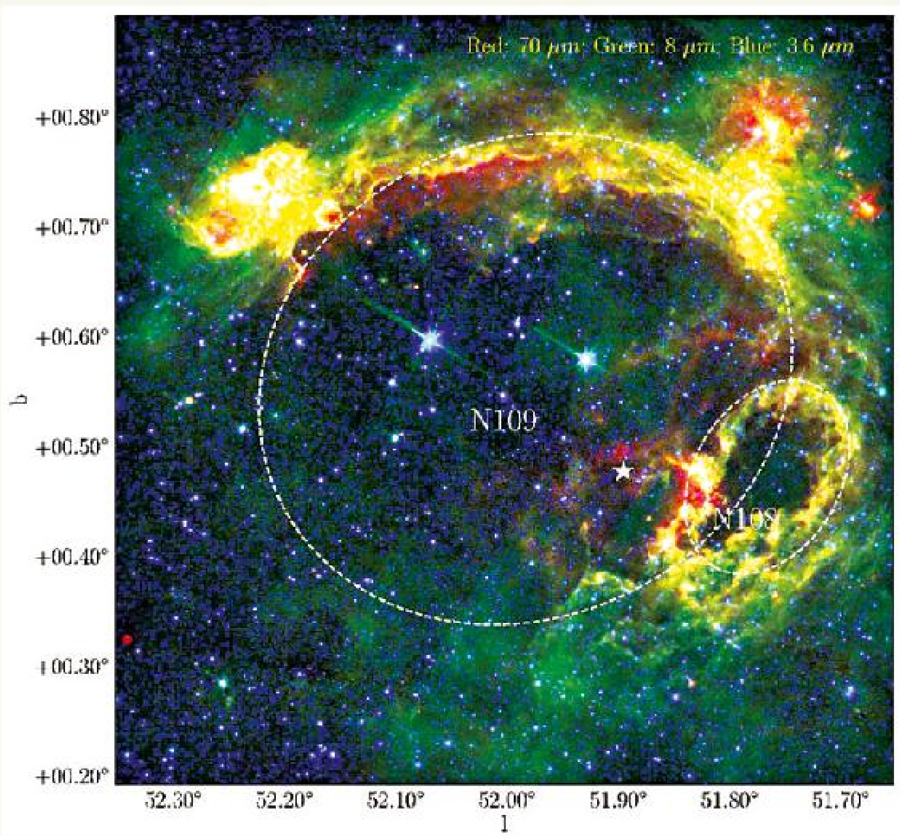


Schematic for strategy to investigate Hyaluronan in body fluids, such as urine and faeces.

Theoretical / Observational Astrophysics & cosmology

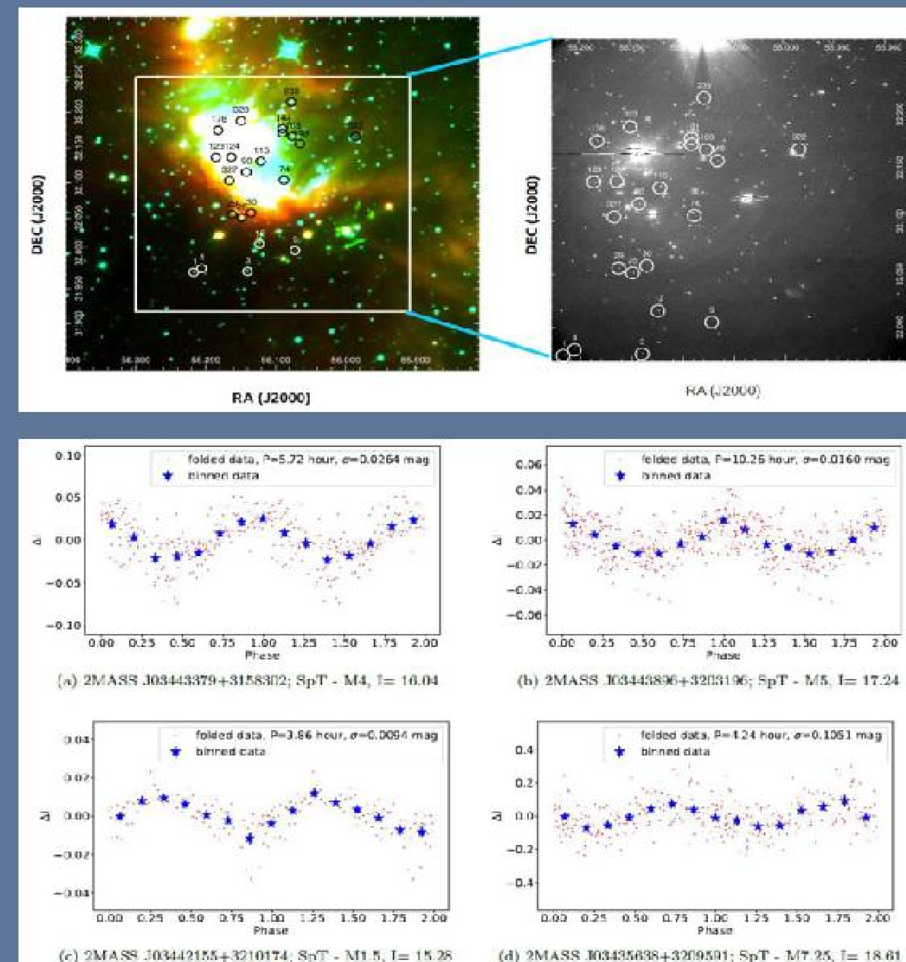
S. N. Bose National Centre for Basic Sciences pursues active research in Theoretical/Observational Astrophysics and Cosmology. Several forefront problems have been addressed for understanding the basic sciences in these areas. Few of the research topics are presented here.

Star-formation and pre-main sequence stars



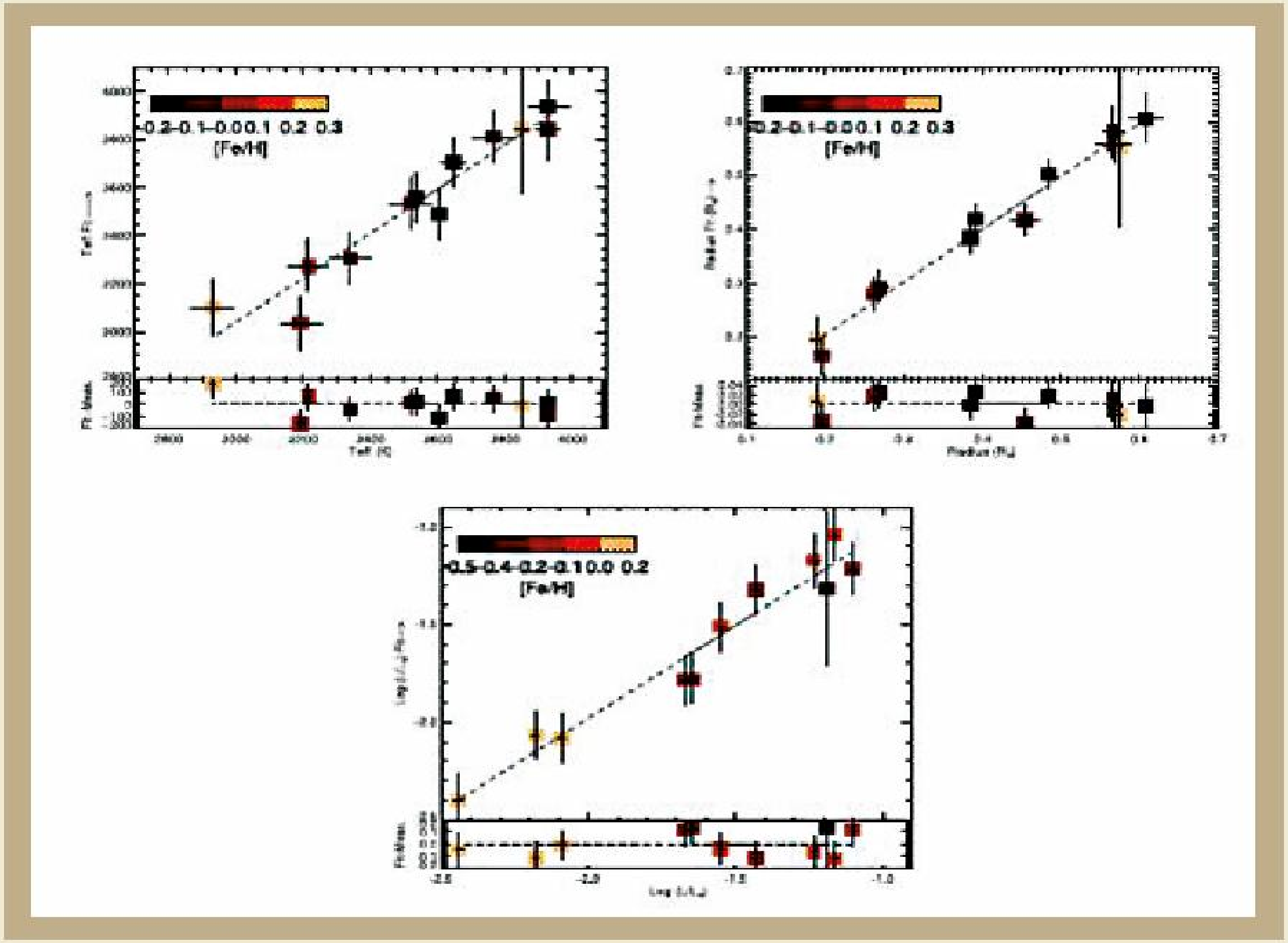
Composite colored image (red: 70μm; green: 8μm; blue:3.6μm) of a Galactic star-forming region.

The physics of star formation and their evolution are best understood by studying objects in young star-forming regions at ages of 1-10 million years. Young clusters with different physical environments and ages help us to understand their formation and evolution process. The properties of disk structures in young stars provide a clue to planet formations. As the pre-main sequence (PMS) stars are generally variable in nature, multi-wavelength photometric variability can be studied to establish a more comprehensive picture of the temporal properties and physical characteristics of PMS objects [1, 2].



Upper Left: Colour composite image of young star-forming IC 348; Upper Right: An image of I-band observations using 1.3-m DFOT, Nainital where young PMS variable candidates are marked in both figures.

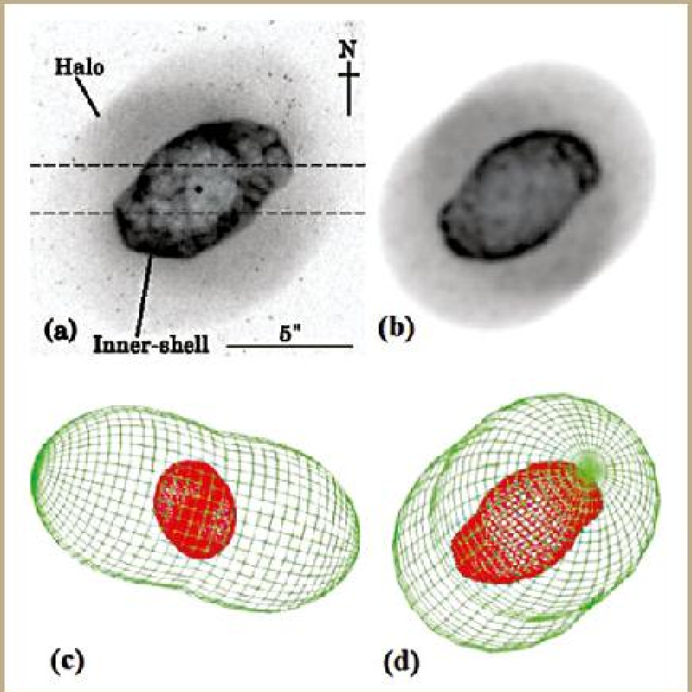
Lower: Phase light curves of the periodic PMS variables are shown in red dots here and blue stars represent the 15-points binned data.



Plots of our best-fitting calibration relationships for temperature (top left), radius (top right) and luminosity (bottom) are shown.

M dwarf stars have masses in the range of about 8% to 50% of the Sun's mass and effective temperature of less than 4000 K. More than 70 percent of all stars in our Galaxy are M dwarfs. Due to their proximity, small size and low mass, M dwarfs are becoming attractive targets for potentially habitable extra-solar planets search. Using medium resolution near-infrared spectra of M-type dwarf stars and K-M giants, new empirical relationships among the fundamental parameters (e.g. effective temperature and surface gravity), spectral indices and equivalent widths of important spectral features like Si I, Na I, Ca I, and 12CO molecular bands have been derived [3, 4].

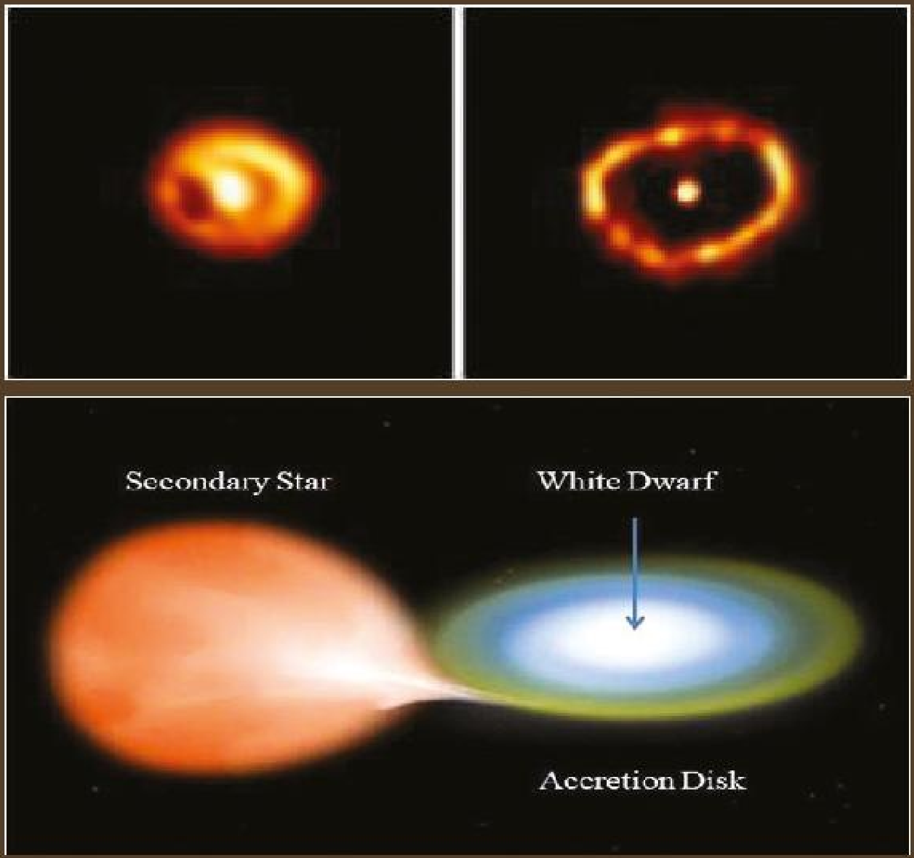
Composite images (X-ray from Chandra telescope & optical from Hubble Space Telescope) of few planetary nebulas (clockwise from top left: NGC 6543 (also known as the Cat's Eye), NGC 7662, NGC 6826 and NGC 7009). Image credit: NASA.



(a) H-alpha image of of a compact planetary nebula PB 1, observed by Hubble Space Telescope. The dotted lines represent position and width of the slit used for HCT spectroscopic observation. (b) The rendered grey-scale 2D model image. (c) The side view and (d) the sky view from the Earth of the constructed 3D model of PB 1 [5].

A **planetary nebula** (PN or plural Pne), is a type of emission nebula that consists of glowing shell of ionized gas ejected from red giant stars. PNe form towards the end of the life cycle of low- to intermediate-mass (~1-8 Msun) stars due to mass loss from their outer layers. The expanding nebula slowly diffuses into the interstellar medium (ISM) and enrich the host galaxy. High-resolution observations reveal very complex morphologies of PNe. The spectrum shows strong lines of H, He, C, N, O, Ne, Ar, S, and Cl as well as features of complex molecules, such as, crys talline silicate, graphite, fullerene & poly-atomic hydrocarbons. However, majority of the PNe remains very less-studied. We have taken up a long-term observational programme to study such PNe in details.

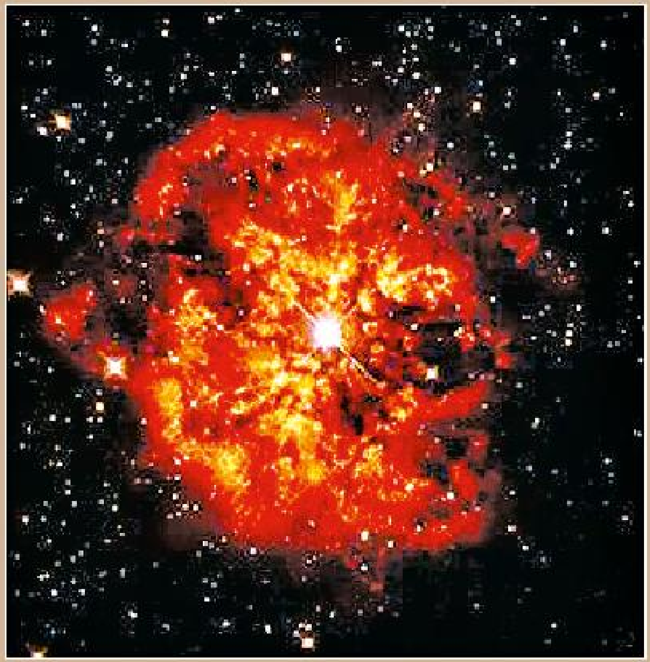
Study the Novae



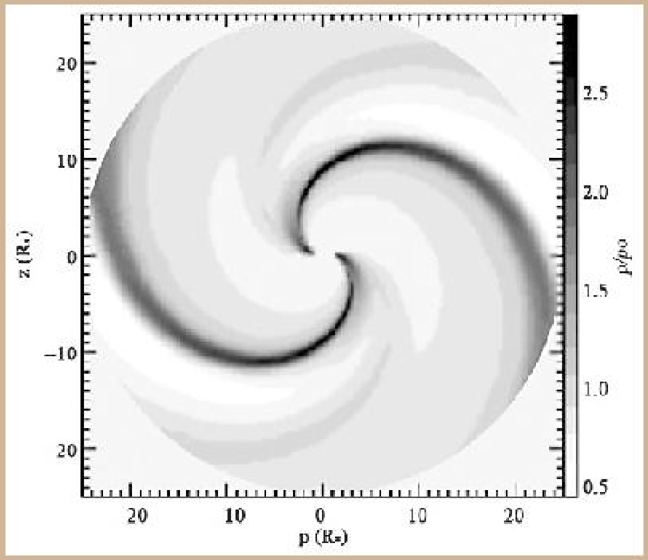
Top: Schematic diagram of a nova binary system. Bottom: Hubble Space Telescope image show the evolution of the shell of material around Nova Cygni 1992 over a period of ~7 months.

Nova ('Novae' in plural) is a close binary system consisting of a white dwarf and a late type star. In the system, the white dwarf accretes hydrogen-rich material from its companion via a disk. Explosions occur on the white dwarf surface due to hydrogen-burning in a very short time scale. Consequently, tremendous amount of energy (~10^45 erg) is released and the system becomes visible from far distance. Novae are used as standard candle to estimate distances in the space. The ejected material enriches the host galaxy. However, the physics of novae is poorly understood. We have taken up a program to study novae. We model the observed spectra to estimate several physical parameters of system to understand the novae phenomena.

Study the wind structure of Wolf-Rayet stars:



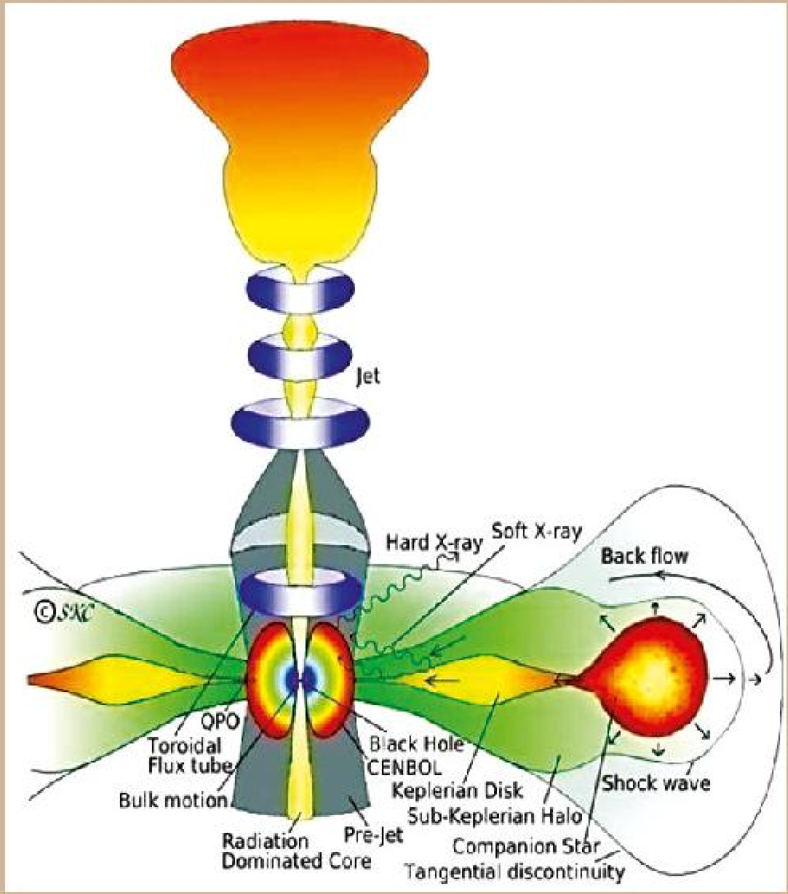
Hubble Space Telescope image of nebula M1-67 around Wolf–Rayet star WR 124.



Schematic of Co-rotating Interaction Region (CIRs) around W-R stars [6].

Wolf-Rayet (W-R) stars are massive (mass >20 Msun) luminous (thousands to millions times the luminosity of the Sun) and extremely hot stars (~30,000-200,000 K). They experience a huge mass-loss (~10^(-5) Msun per year) with terminal velocities in the range from 750-5000 km ~S^(-1). Wind of W-R star is known to be highly clumpy and non-uniform in nature because of the presence of co-rotating interaction regions (CIRs) in their winds. These clumpy winds might have a large impact on their mass-loss process and thus, on how they end their lives. High-resolution (Resolving power~30000) spectroscopic monitoring observations of W-R stars may help us to understand such phenomena.

Properties of Black-hole companions



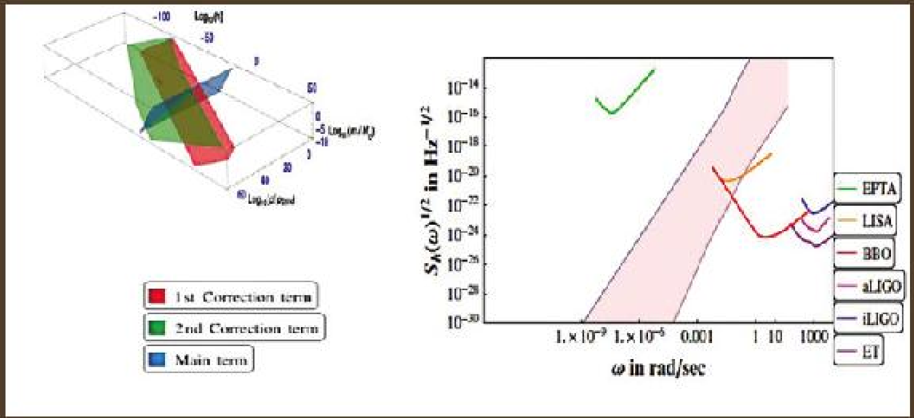
Schematic diagram of the accretion process around a black hole.

Black holes are black, because they do not emit any radiation. However, the matter, tidally pulled by them from their companions, produces accretion disks around black holes and emits X-rays and gamma rays. The well accepted picture is that the soft X-rays are produced by standard Keplerian disks and hard X-rays are produced by a hot electron cloud. The companion is supplying both Keplerian (yellow/red) and sub-Keplerian (greenish) matter to the black hole. In our Galaxy already more than two dozens of stellar mass black holes have been identified [7]. However, predictability of X-ray emission is poor as the companion's properties are largely unknown. Once we know the mass-losing properties of the companion, we will know the outer boundary condition of the accretion disks more precisely.

Dark Energy from various approaches

Explaining the observed present acceleration of the Universe is one of the most challenging problems in contemporary physics. Using scalar field models it has been shown how both early inflation and late time acceleration can emerge within a unified framework that may account for both dark matter and dark energy. Results from other approaches, such as through backreaction of inhomogeneities, and even quantum entanglement, have been obtained and compared with the scalar field approach, vis-a-vis constraints from observational data on the various model parameters. [8,9]

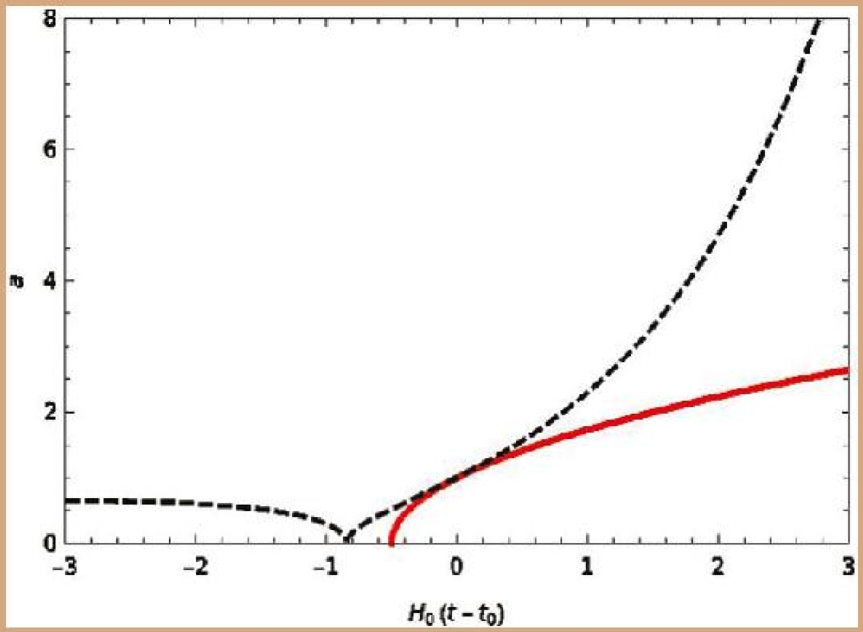
Equivalence Principle, Gravitational Lensing & Gravitational Waves



Detectability of Stochastic background of Gravitational Waves.

The status of the weak equivalence principle at the quantum level is an unsolved mystery. It has been shown how the naive classical concepts may get modified leading to observational imprints at high energy scales. Interesting phenomenological implications have been obtained due to Gravitational Lensing by primordial black holes. Binaries of primodial black holes produce a stochastic background of gravitational radiation, which is very relevant to the recent observations of gravitational waves [10,11].

Cosmology from the renormalization group flow approach to gravity



Scale factor vs cosmic time.

Cosmology is a branch of physics which aims in the fundamental understanding our Universe. General relativity has been extremely successful as the theory of low energy, long distance gravitational interactions and has led to detection of gravitational waves. However, it has been realized that no consistent quantization of general relativity exists at a perturbative level because of the dimensionful nature of the gravitational coupling. A new functional renormalization group (RG) approach is introduced to quantum gravity. Using this 'RG-improved' Einstein's equation the Friedmann-Lemaitre-Robertson-Walker (FLRW) model of cosmology has been studied recently, leading to coupled ordinary differential equations for the scale factor, the density, Newton's constant, cosmological constant.

Eqn 1: Einstein's equation.

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

References:

[1] *ApJ* **2021**, *910*(1), 80

[2] *ApJ* **2018**, *864*(2), 154

[3] *AJ* **2021**, *161*(4), 198

[4] *MNRAS* **2020**, *493*(3), 4533

[5] *MNRAS* **2020**, *496*, 814

[6] *ApJ* **2009**, *698*(2), 1951

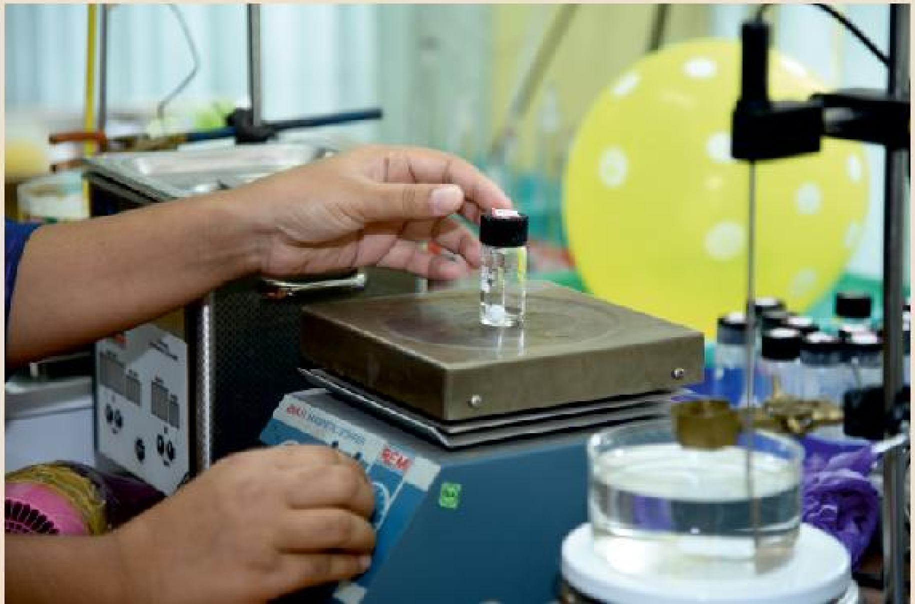
[7] *ApJ* **1995**, *455*, 623

[8] *Gen. Rel. Grav.* **2013**, *45*, 1971

[9] *JCAP* **2017**, *01*, 054

[10] *Class. Quant. Grav.* **2012**, *29*, 025010

[11] *Phys. Rev. D.* **2019**, *100*, 103514



Computational Material Science: Mechanism, Prediction and Rational Design

One of the success stories at SNBNCBS is the creation of a state-of-art computational data center housing high performance supercomputing cluster of 200 TeraFlops, which during the time of installation (May 2014) was the largest in Eastern Indian and third largest in India. The facility has been subsequently upgraded and listed within top 50 supercomputers in India based on the survey carried out by CDAC Bangalore. The users of the computational resources involve not only in-house users, but also external users especially those from far-east.

SNBNCBS has developed significant strength and international reputation in the broad area of theoretical and computational modelling and simulation of complex systems ranging from quantum materials to biological processes with 8 faculty members and a large group of post-doctoral scientists and research scholars working in this area.

Structure and dynamics of complex systems span an enormous range of length and time-scales. We have in-house expertise in different classes of computational modelling approaches to tackle the complexity in these systems. At the smallest time and length scales, sophisticated electronic structure calculations are employed to understand important chemical interactions and material properties. At higher time and length scales, the use of classical molecular dynamics simulations provides insight into the dynamics and transport in large assemblies of molecules including biopolymers. Multi-scale modelling approaches like QM/MM and coarse graining is used to study chemical reactions in complex molecular environments like enzymes or to understand the behavior of bio-materials at nano-bio interfaces. Theoretical modelling of various non-equilibrium transport processes observed in nature as well as cellular processes at length and time scales beyond the scope of atomistic modelling are treated within the framework of statistical mechanical and kinetic modelling approaches. Such models help us to establish a direct connection with experimental results and provide fundamental mechanistic insights related to these processes.

There are three major sub-themes under the umbrella of activities in Computational Material Science:

Electronic Materials at Bulk & Nano Scale:

Quantum Materials are governed by the electrons, one of the fundamental building blocks of materials at microscopic length scale, and the glue that binds atoms together. Research has been devoted in understanding electronic properties in bulk and nanoscale, developing the structure-property relations, prediction of new functionalities in known materials, and predicting new materials all together. Some of the key activities in this area are:

- Understanding the novel magnetic behavior in quantum spin systems
- Understanding of cooperativity and hysteresis in metalorganic spin crossover compounds.
- Understanding properties at interfaces of transition metal oxides
- Electronic, magnetic and phase stability of clusters.
- Control in graphene magnetism through adatom and creation of open edges.
- Many body interactions in confined electrons

Complex Fluids

Complex fluids are composed of a variety of components. One of the specific examples related to complex fluids is colloids, which are micron sized particles in dispersion, performing Brownian motion. The example of colloid ranges from examples in day to day life like blood, milk, paint etc to that in laboratory which are charge stabilized colloids. Our researchers addressed the dynamics of such particles in presence of confining walls and external laser modulation.

A few of the major activities in this area are:

- Study of microscopic reorientation mechanisms involving pronounced jumps.
- Dynamic heterogeneity and collective dynamics in complex systems, e.g. water in presence of a protein denaturing agent, Ionic Liquid (IL) upon addition of water, water under confinement
- Non-equilibrium effects in active Brownian particles, bacterial chemotaxis, coupled non-equilibrium systems, growth of actin filaments.

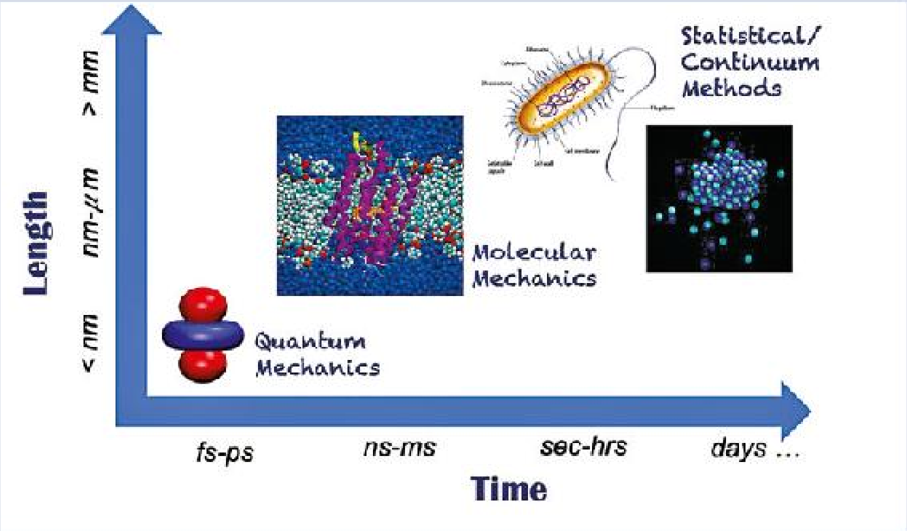
Biological materials:

Biological materials are natural biocompatible materials that constitute a whole or a part of a living structure or biomedical device that performs, augments, or replaces a natural function. In this connection, bio-macromolecules may provide unique systems which can be fabricated to design novel materials.

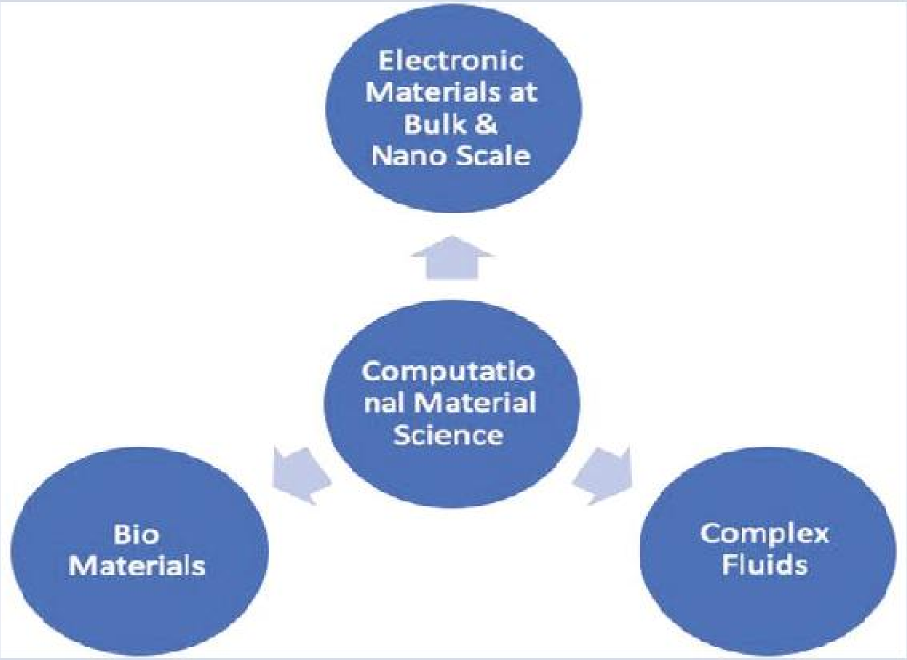
Fully atomistic classical molecular dynamics simulations of several hundreds of nanoseconds with tens of thousands of atoms have been carried out to investigate:

- Response to chemical and light induced changes in proteins
- Functional ligand binding in proteins
- Structural reconstruction of bio-molecular fragments
- Dynamical correlations in proteins

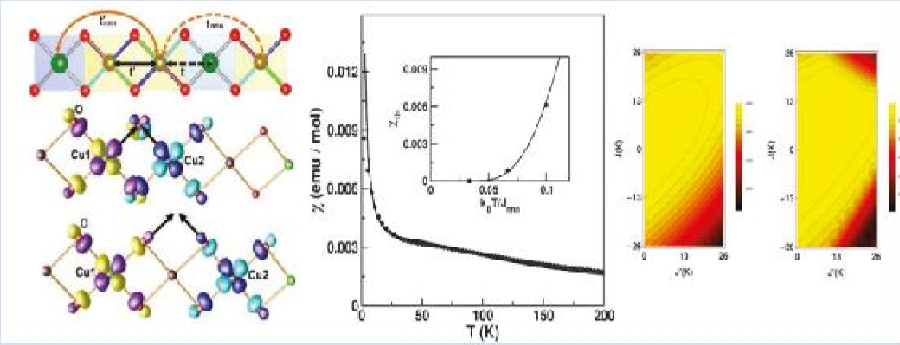
High performance computing (HPC) facility: Cray supercomputer (200TF)



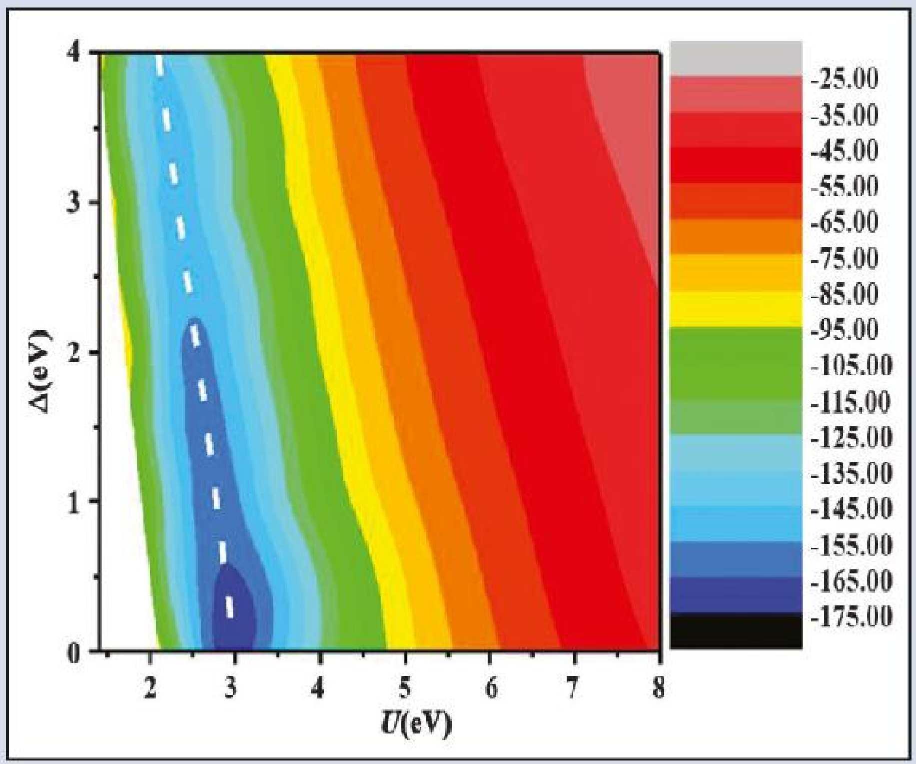
Multi-scale modelling and simulation of complex systems across a wide range of length scale and time scale



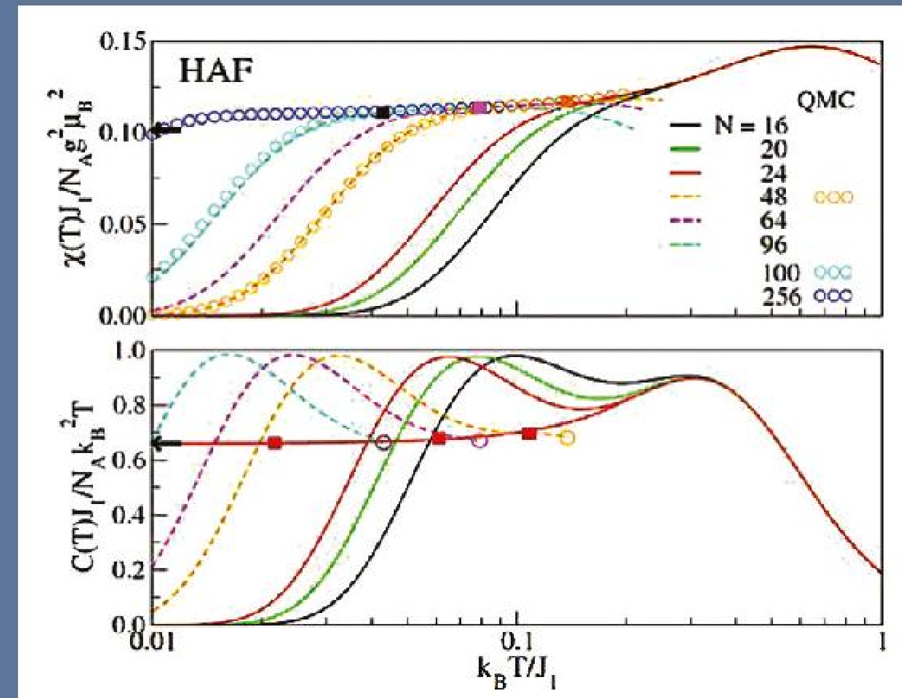
Three major sub-themes



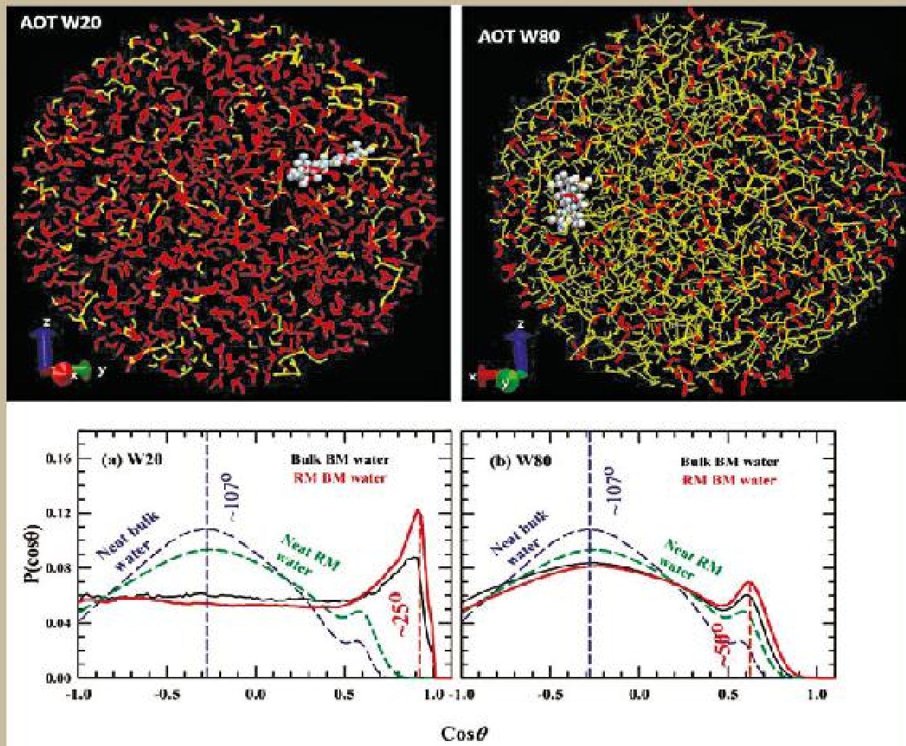
(Left) Overlap of effective Cu Wannier functions in a spin compound. (Middle) The calculated magnetic susceptibility of the derived spin model. (Right) The spin gap in the parameter space of J and J : (Phys. Rev. B, 2018, 98, 144412)



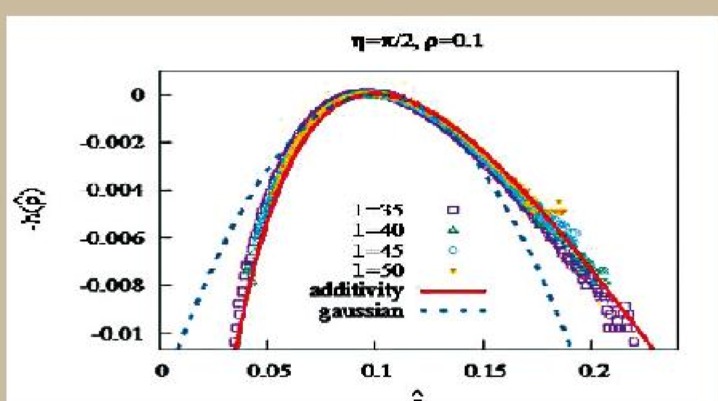
The determined Neel temperature upto a multiplicative constant for 4d transition metal oxides in the Coulomb interaction strength (U) and charge transfer energy () plane. (Phys. Rev. B **86**, 104406 (2012))



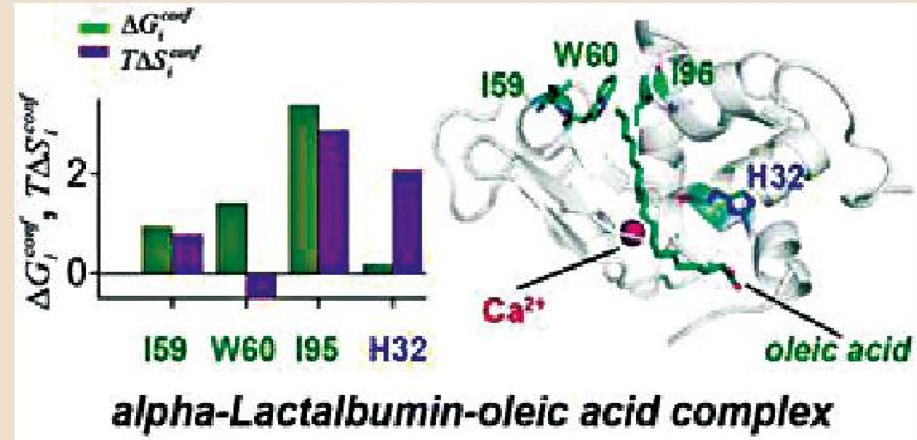
HAF results for magnetic susceptibility, x(T) (upper panel) and C (T)/T(Lower panel) where C(T) in the specific heat. Solid and dashes lines are ED and truncated DMRG, respectively, at the indicated system size N. The QMC calculation of x(T) are shown by open symbols. The arrows are exact at T20 (Phys. Rev. B 101054411, 2020)



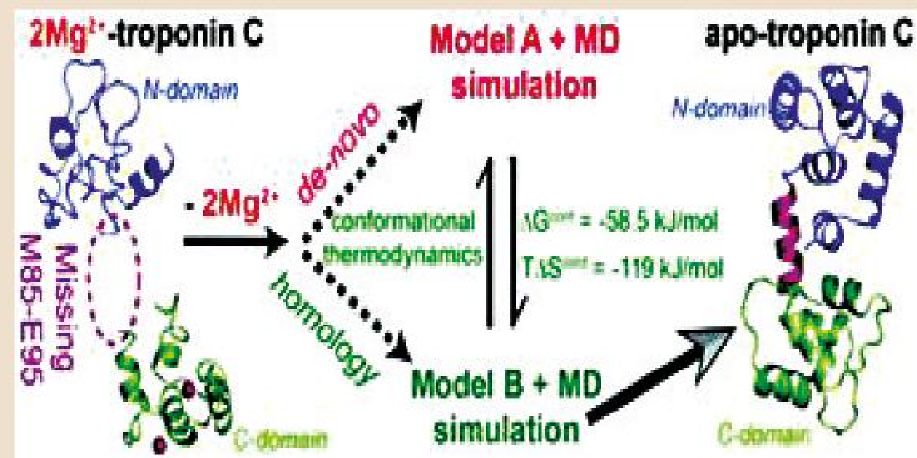
Computer simulation results for confined water and methanol mixtures at 20:80 and 80:20 ratio. Solute (coumarin 153) locations are explicitly shown in these systems which is 'nearly' insensitive to confined medium composition. Water tetrahedral structure is highly perturbed upon mixing with methanol in bulk phase itself, which, upon confinement, undergoes further distortion.



Coarse-grained density distribution in the two-dimensional Vicsek model. (Physical Review E **99**, 052604 (2019))



Alpha-Lactalbumin-oleic acid complex (Mol Biosyst **10**, 3280 (2014))



Structural reconstruction based on conformational thermodynamics (Mol Biosyst **12**, 444 (2016))

Ultrafast and High-Resolution Spectroscopy

Research on ultrafast and high-resolution spectroscopy has evolved as one of the key experimental thrusts at the S. N. Bose Centre during the last two decades and earned worldwide recognition in this field of interest. Experimental groups from two departments: Condensed Matter Physics and Material Sciences (CMPMS) and Chemical Biological and Macromolecular Sciences (CBMS) are involved in establishing some state-of-the-art experimental facilities which are certainly unique in the country, if not worldwide. Some of these unique facilities include: time-resolved magneto-optical Kerr effect (TR-MOKE) microscope, conventional and micro-focused Brillouin light scattering (BLS), broadband ferromagnetic resonance (FMR), spin-torque FMR (STFMR), dielectric relaxation spectroscopy (DRS), terahertz time-domain spectroscopy (TTDS), cavity ring-down spectroscopy (CRDS) and evanescent wave-coupled CRDS techniques with the latest quantum cascade laser (QCL), time-resolved fluorescence spectroscopy (TRFS), microfluidics etc.

A research team from the CMPMS department have carried out pioneering research in the fields of ultrafast spin-dynamics, magnonics, spintronics and spin-orbitronics for more than a decade. They indigenously developed the TR-MOKE microscope, conventional and microfocused BLS, broadband FMR, STFMR, DRS and TTDS besides a number of thin film deposition and nanofabrication facilities. These make the group unique in India and worldwide for research in ultrafast spin dynamics and magnonics. They have developed numerous novel experimental methods, including benchtop TRMOKE and all-optical detection of spin Hall effect and spin pumping, which are regarded very highly internationally. Few recent developments are listed below.

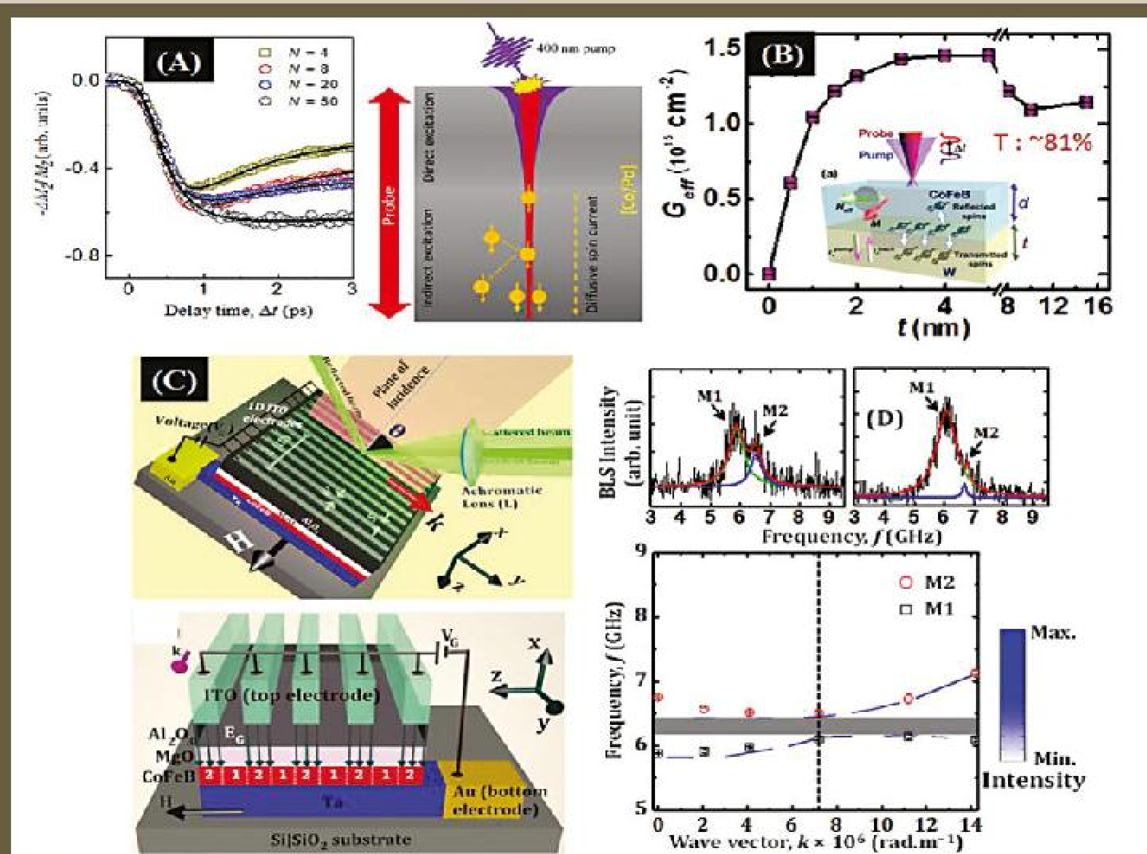
a. Ultrafast demagnetization in magnetic thin films and multilayers: The ultrafast demagnetization is one of the most debatable and rich phenomena for nearly three decades and yet a consensus on the underlying mechanism has not been established. They are important for optical manipulation of spin in femtosecond timescale and application in all-optical data writing. This group has done some outstanding work showing clear evidences of co-existence of direct and indirect mechanisms [1], role of Fermi level tuning [2] and spin current transport

A. Time-resolved magneto-optical Kerr effect (TR-MOKE) microscope. B. Conventional backscattered (left panel) and micro-focused (right panel) Brillouin light scattering (BLS) setups. C. Ultrafast spectro-microscopy lab showing the femtosecond amplified laser, 2nd & 3rd harmonic generator and optical parametric amplifier (left panel) and optical pump-probe spectroscopy (right panel) setup. D. Broadband (left panel) and spin-torque (right panel) ferromagnetic resonance (FMR) setups.

in ultrafast demagnetization in Co/Pd multilayers, Heusler alloys, graphene/ferromagnet heterostructure and synthetic antiferromagnets.

b. Spin-charge conversion for pure spin current generation: Efficient generation and transport of pure spin current will revolutionize future energy-efficient and miniaturized magnetic storage, memory and logic devices and this group has made remarkable contributions in highly efficient generation and transport of pure spin current using spin-Hall effect [3], and spin pumping [4] in heavy metal (2D material)/ferromagnet heterostructures using all-optical methods. Observations of high spin-Hall angle (>0.4) and more than 80% interfacial spin transparency of β-W in β-W/CoFeB heterostructure by this group project this system as a key material for future spin-orbitronic applications.

c. Reconfigurable and reprogrammable magnonics: This group has made extensive contributions in the development of reconfigurable magnonics [5-8] for GHz and sub-THz frequency on-chip data communication and processing. In a recent work they have developed on-demand reprogrammable magnonic nanochannels by electric field (voltage) controlled magnetic anisotropy [9].



A. Ultrafast demagnetization in [Co/Pd]N multilayers showing evidences of direct (spin-flip scattering) and indirect (thermal current) demagnetization mechanisms. B. All-optical measurement of spin pumping in W/CoFeB showing giant interfacial spin transparency (T) of > 80% in β-W phase. C. Development of electric field controlled on-demand magnonic nanochannels.

References: [1] *Phys. Rev. B.* **2018**, *98*, 214436. [2] *Phys. Rev. B.* **2020**, *101*, 224412. [3] *Phys. Rev. B.* **2017**, *96*, 054414. [4] *Sci. Adv.* **2019**, *5*, eeav7200. [5] *ACS Nano* **2011**, *5*, 9559. [6] *ACS Nano* **2012**, *6*, 3397. [7] *Adv. Funct. Mater.* **2013**, *23*, 2378. [8] *ACS Nano* **2017**, *11*, 8814. [9] *Sci. Adv.* **2020**, *6*, eaba5457.

A group of scientists from the CBMS department have developed several high-resolution cavity-enhanced optical spectroscopic techniques such as cavity ring-down spectroscopy (CRDS) and evanescent wave (EW)-coupled CRDS techniques with the latest quantum cascade laser (QCL) technology for a variety of applications in biomedical and environmental sciences as well as for studying fundamental molecular spectroscopy both in gas and condensed phases. Such facilities are one of the very first of its kind in India. The team has applied these techniques to understand and explore various chemical phenomena like nuclear spin isomers, spin chemistry and isotopic fractionations in chemical reactions along with for non-invasive clinical diagnosis by means of human breath test. In recent years, this group has also developed the "Quantum Weak Measurement (QWM)" technique for the measurement of optical beam shifts in various materials exploiting the concept of quantum mechanics. The group is also currently exploring the optical spin Hall effect in 2D materials via QMW method.

Students performing various high-precision spectroscopic experiments such as CRDS, EW-CRDS, QCLS and QWM

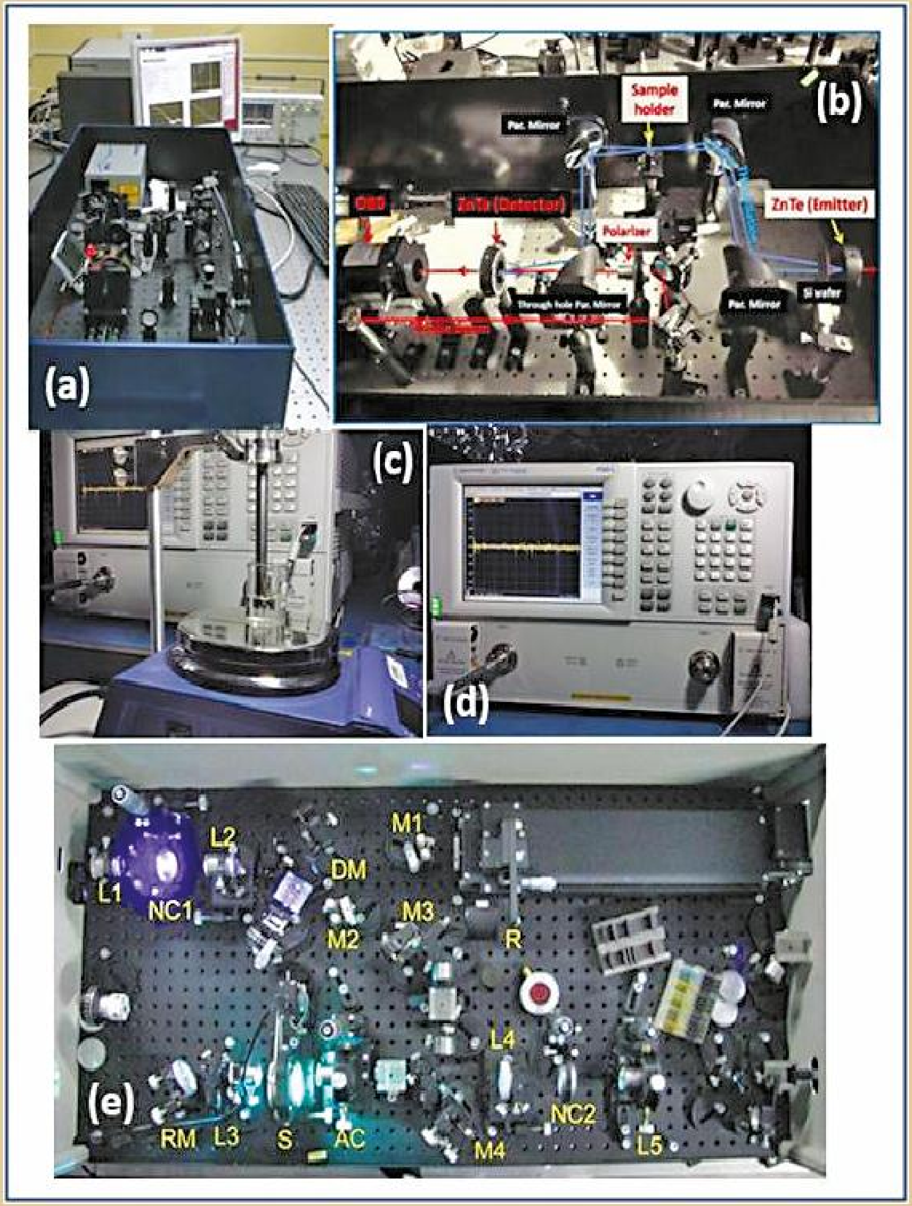
Another group at CBMS department has established a THz-time domain (TTDS) experimental facility with special reference to the measurements of soft matters (aqueous based, e.g. self-assembled aggregates, biomolecules like proteins, DNA, vesicles etc.). Such measurement facility is one of the rare, if not the solitary, in India and globally such facilities are also sparse.

This group has revisited a few hypotheses accepted in the scientific community based on conventional experiments. The uniqueness of THz spectroscopy in the form of label-free identification of hydration dynamics as well as retrieving the low-lying collective vibrational features of water network structure, which are otherwise wiped off in conventional spectroscopic techniques. This enables one to redefine the age-old fundamental 'structure breaker' and 'structure maker' concept of water in the light of "Hofmeister effect" [10]. This group has combined dielectric spectroscopy in GHz-THz region, fs-resolved pump-probe, fluorescence spectroscopy as well as MD simulation investigation to underline spatial and temporal heterogeneity in various mixed solvents [11].

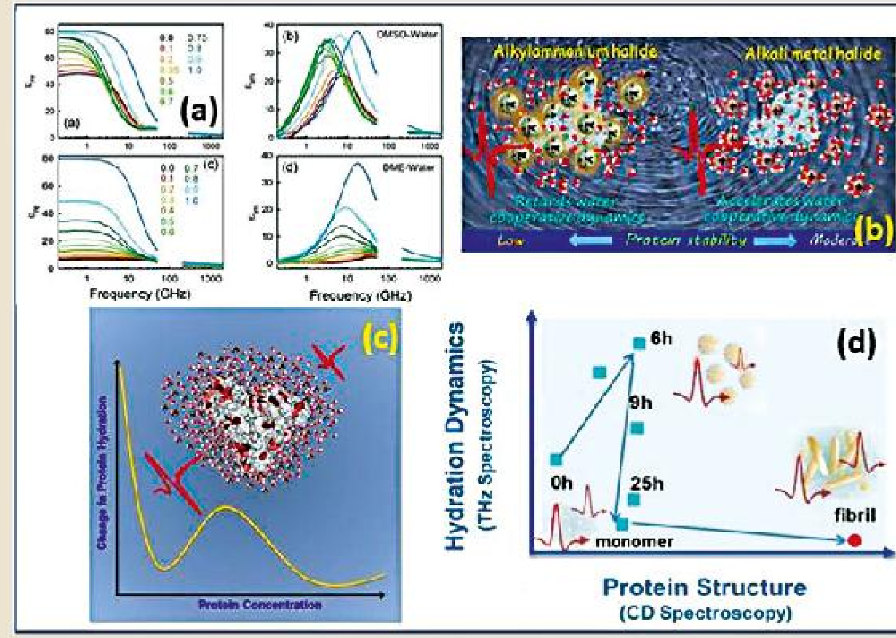
Their results have established that, instead of being a mere spectator, water does extensively slave protein folding phenomenon. Their study has revealed the hydration dynamics of a membrane and the effect of the membrane charge type on it [12]. Using terahertz spectroscopy, this group have established the alteration of the collective hydration of water during the fibrillation process (native $\rightarrow$ intermediate $\rightarrow$ fibril) of a model protein [13]. This study is one of the first experimental demonstrations of hydration change during such processes. A sharp change in the hydration, as observed in these experiments, could be found promising to detect protein fibrillation at its early stage.

This group has also been involved in the studies of interaction between nano-composites and THz radiation, such studies in addition to cater fundamental understanding of the inherent mechanisms, could yield commercial implications [14].

References: [10] *J. Mol. Liq.* **2016**, *215*, 197; *PCCP* **2014**, *16*, 23308; *J. Phys. Chem. B.* **2017**, *121*, 7777; [11] *J. Mol. Liq.* **2019**, *290*, 111194; [12] *J. Phys. Chem. B.* **2018**, *122*, 5066; [13] *Chem. Comm.* **2021**, *57*, 998; [14] *Opt. Lett.* **2017**, *42*, 1764.



(a and b) THz time domain spectroscopy set-ups. (c and d) Dielectric relaxation spectroscopy (VNA) set-up. (e) fs-resolved fluorescence spectroscopy setup.

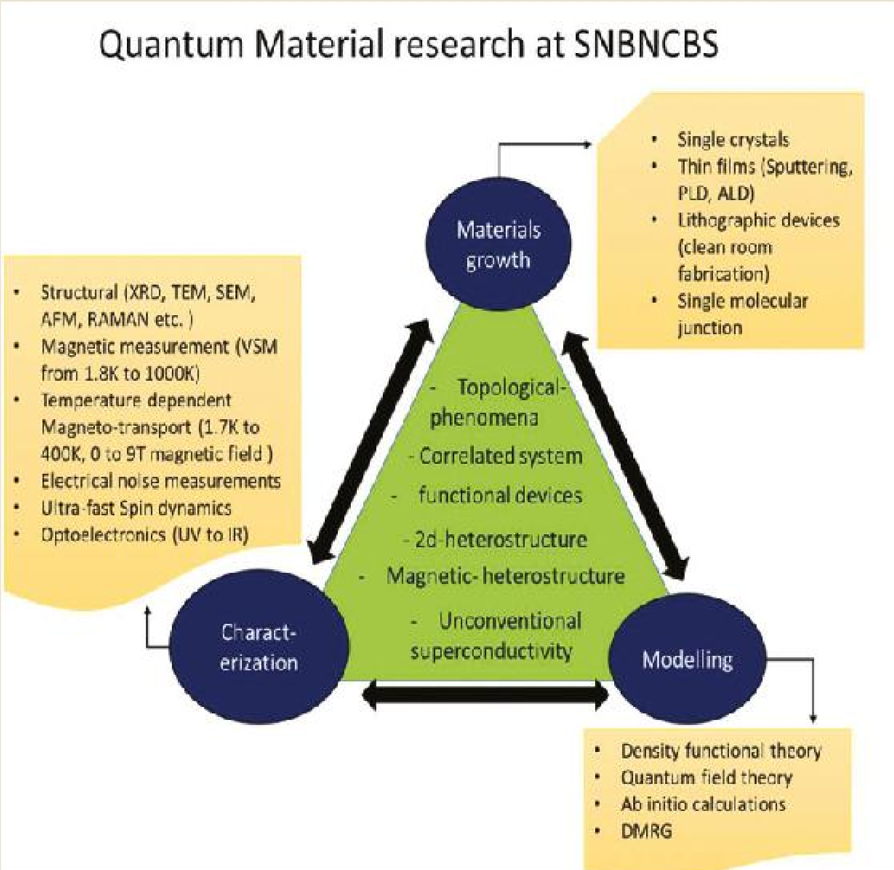


(a) Real and imaginary parts of dielectric constant(s) of in 0.2 - 50 GHz and 0.3 - 1.6 THz region. (b) Contrasting collective solvation of a protein in presence of alkali metal halide and alkylammonium halide. (c) THz absorption shows an oscillating behavior with protein concentration in water-alcohol mixture. (d) Change in protein collective hydration as it aggregates to form fibrils.

Emergent quantum materials and devices

1. Introduction

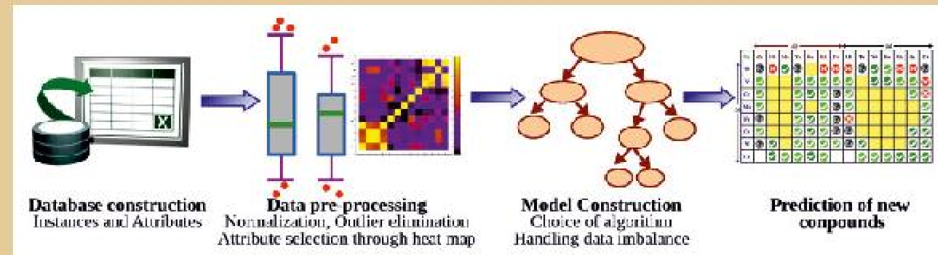
'Quantum materials' refers specifically to those materials whose characteristic behavior is rooted in the quantum world, with no classical analogue. Inside materials, emergent phenomena are often seen due to the interaction of electronic states characterized charge, spin, orbitals degrees of freedom, combined with their topological character. These materials exhibit many macroscopic quantum phenomena, such as ferroelectricity, piezoelectricity, superconductivity, magnetism and energy storage. These special properties make these materials play a major role in modern society, having wide range of impact in communication, energy storage, sensing and bio-medical applications. SNBNCBS is actively working on many areas of quantum material research, as summarized in following image.



2. Design, Prediction and Growth

2.1 Understanding and prediction of quantum materials

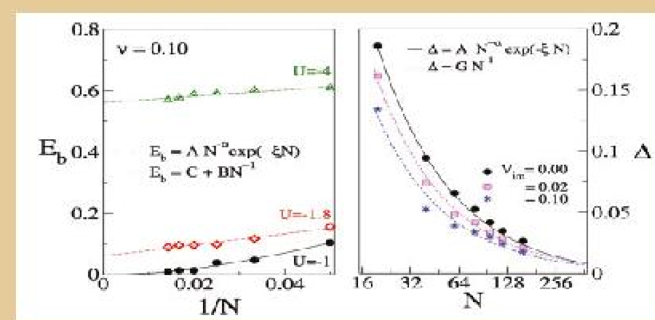
Understanding & prediction on Quantum Materials need collaborative efforts between Advanced Instrumentation, Materials synthesis and Modeling and Simulation. A major activity of our center is in the area of *Quantum Materials Simulation and Prediction,* with objectives such as, a) to understand the structure-property relations in known materials exhibiting properties dominated by quantum effects, b) to predict new functionalities in know materials and c) accelerated design and discovery of novel materials, via a materials' informatics platform of database-driven high-throughput quantum simulations.



Machine learning scheme for new materials prediction (Phys. Rev. Materials 3, 084418; npj Quantum Materials, 3, 17).

2.2 Predicting new quantum phases

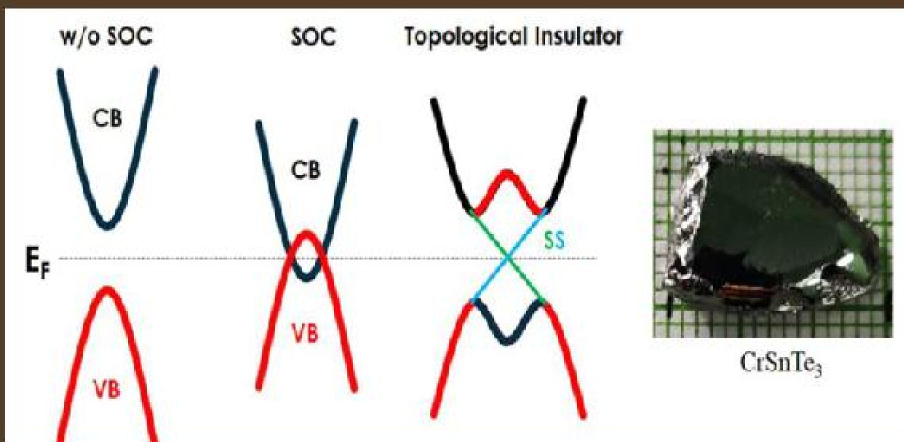
Our center is also involved in predicting and exploring the new quantum phases in the model systems and applying these concept in real materials. Unfortunately most of these systems are strongly correlated systems and involves dealing with exponentially increasing Hilbert space with system size. We use various numerical tools like density matrix renormalization group method, exact diagonalization and other sophisticated numerical technique to solve these problems. Recently we explore the effect of magnetic field on the one dimension superconductors in a parabolic potential. This system isexpected to create a topological phase with localized Majorana zero energy edge modes in this system. We find a parameter regime in the model which showed exponentially decaying energy gaps as a function of the system size (as shown in Figure a), which is generally associated with localized zero energy modes in the system. However, further examination of this exponential degeneracy in presence of impurities showed that it is susceptible to local perturbations in the bulk (Fig. (b)) and the edge modes are not robust.



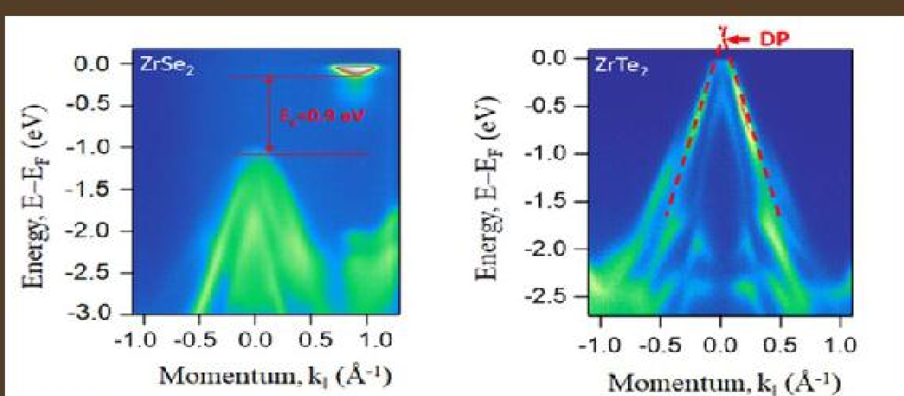
(a) Scaling of binding energy as a function of system size for different on-site interactions U, and (b) semi-log plot showing scaling of lowest energy gap as a function of system size in presence of impurities V_{im}. Phys. Rev. B **102**, 125135 (2020).

2.3 Synthesis of Topological Quantum Materials

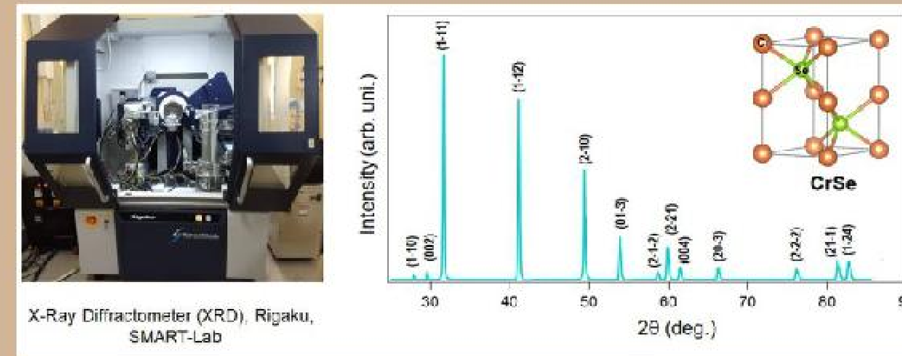
Condensed matter systems have recently become the fertile grounds for discovering various emerging topological quasi-particles within the symmetry protected modes. Therefore, from the recent past, the basic research of condensed matter physics or materials sciences is skyrocketing in designing and synthesizing many new exotic topological systems for their potential applications in quantum computations and spintronics. Specifically, the experimental observation of topological insulators with Dirac fermions near the Fermi level on the sample surface was a gigantic discovery in the field of condensed matter physics during the last decade.



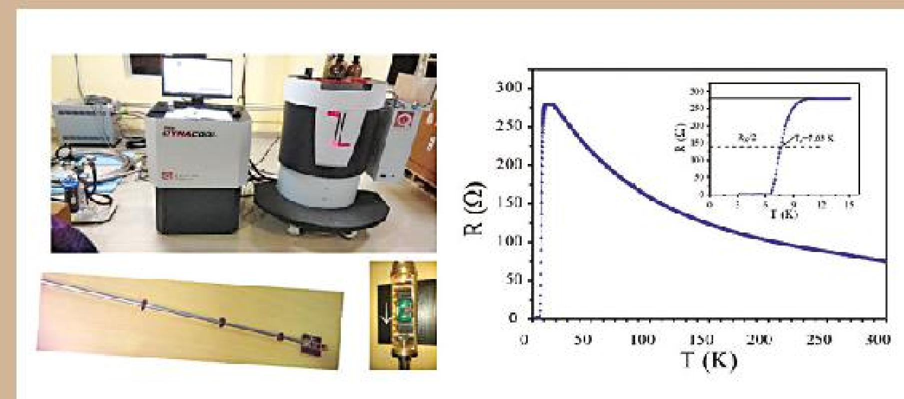
Transformation of an ordinary insulator into a topological insulator under the spin-orbit coupling (SOC). Right panel shows a photograph of a single crystal grown at SNBNCBS.



Electronic Band Structure [I. Kar et al., PRB 101, 165122 (2020)].



Structural Characterization of CrSe using XRD machine.

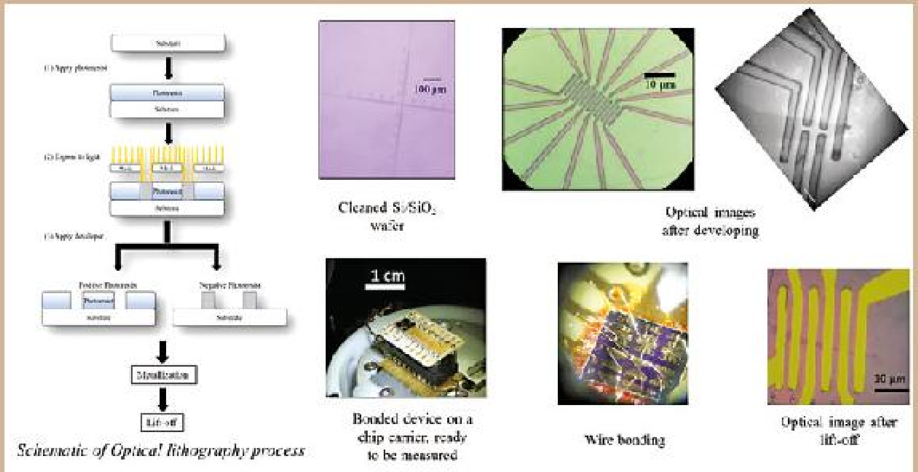


Physical Property Measuring System (PPMS-Quantum Design)

Resistance vs. Temperature graph of NBN thin film showing superconducting transition at 7.63K

2.4 Fabrication of lithographic devices

Clean room based Nanofabrication facilities at SNBNCBS.

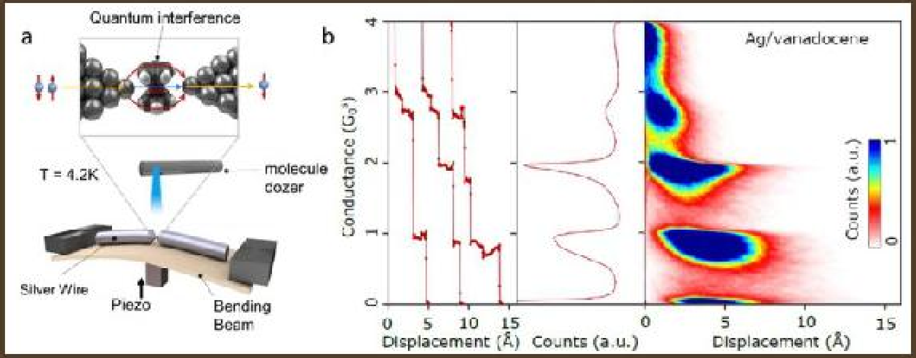


Creation of micron size device on a chip using optical lithography

Student performing optical lithography in the Mask aligner.

2.5 Creating and measuring a single molecular device

As the size of the transistor going towards the few nanometer scale, there is surge in the research community to understand the electrical, thermal properties in the atomic limit. A single organic molecule suspended between two metallic electrodes is an attractive electronic device since it allows using the rich structural possibilities of organic molecules to manipulate electronic conductance at the nano-scale. We approach this problem by creating atomic or molecular junctions with mechanical break junction techniques. This will allow us as a test-bed for the fundamental principles to study charge and spin transport across individual molecules. This approach is especially attractive because of the freedom to affect transport at the atomic-scale by the structural variety of organic molecules and their hybridization with the electrode. We aim for a better understanding of the involved transport mechanisms in molecules and we will look for general principles for charge and spin manipulations across individual molecules. Our recent experiments show that that spin-polarized currents can be generated at the single molecule level by putting a magnetic molecule between two nonmagnetic silver electrodes *(Nature Communications. 10, 5565, 2019).*



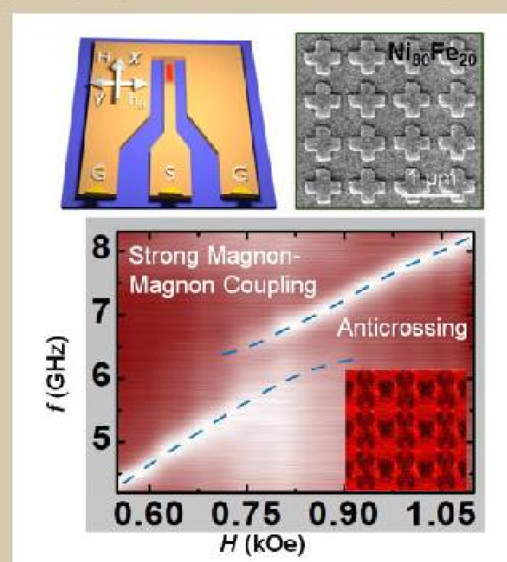
(a) Schematic of the Mechanically controllable Break junction (MCBJ) set up (bottom). Spin filtering due to spin dependent quantum interference in different molecular orbitals is depicted schematically (top). (b) Characterization of Ag/vanadocene molecular junctions. Left panel: examples for conductance versus inter-electrode displacement traces recorded at a bias voltage of 100?mV, with traces shifted in the displacement axis for clarity; Middle panel: conductance histogram constructed from 5,000 conductance traces; Right panel: conductance-displacement density plot based on the same conductance traces.

3. Applications of quantum phenomena

3.1. Quantum Systems for Spin-Based Technologies:

Quantum technology has made tremendous inroads during last two decades. Integration of different quantum modules leads to *hybrid quantum systems,* harnessing advantages of complementary quantum phenomena and deriving new functionalities. A research team have developed *quantum hybrid systems based on magnon-phonon and magnon-magnon interactions.* In the first case, the acoustic waves and spin waves were generated in a two-phase multiferroicnanomagnet grown on a piezoelectric substrate. The coupled magneto-acoustic dynamics unraveled the hybrid magneto-elastic modes with unique characteristics different from constituent magnon or phonon [1]. Besides, strong magnon-magnon coupling were demonstrated in arrays of ferromagnetic nano-cross elements where magnetic dipolar coupling aided by microwave power led to avoided crossing of magnon frequency branches a marker of strong coupling in hybrid systems [2].

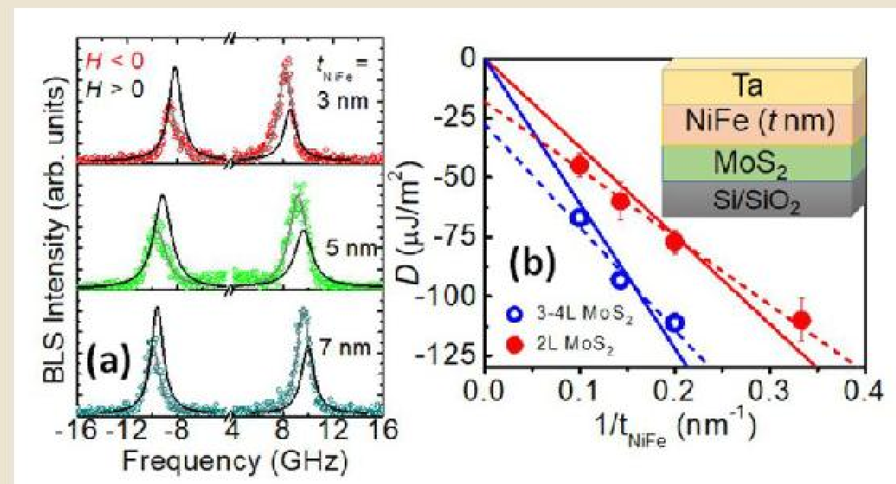
2D materials/ferromagnetheterostructures show unusual quantum and topological properties useful for future spintronics. This team



Dipolar interaction mediated strong magnon-magnon coupling in a ferromagnetic nano-cross array. Applied magnetic field dependence magnon frequency reveals avoided crossing characteristic of the strong coupling.

have discovered unusual interfacial Dzyloshinskii-Moriya interaction (iDMI), an asymmetric exchange interaction, which may lead to the formation of chiral and topological spin textures like skyrmions. They employed Brillouin light scattering spectroscopy to study the non-reciprocal spin-wave dispersion in graphene/ferromagnet [3] and MoS2/ferromagnetheterostructures [4] and discovered sizable iDMI in both systems originatedfrom defect-mediated extrinsic spin-orbit coupling at the interface in these systems.

1. S. Mondal et al. ACS Appl. Mater. Interfaces 10, 43970 (2018); 2. K. Adhikari et al. Phys. Rev. B 101, 054406 (2020); 3. A. K. Chaurasiya et al., Phys. Rev. B 99, 035402 (2019); 4. A. Kumar et al., Appl. Phys. Lett. 116, 232405 (2020)



(a) Spin-wave asymmetry revealing the presence of interfacial Dzyaloshinskii-Moriya (iDMI) interaction in MoS_2/NiFe/Ta heterostructures. (b) Variation of DMI strength with NiFe thickness for 2L and 3-4L MoS_2.

3.2 Optoelectronics devices and light-matter interaction

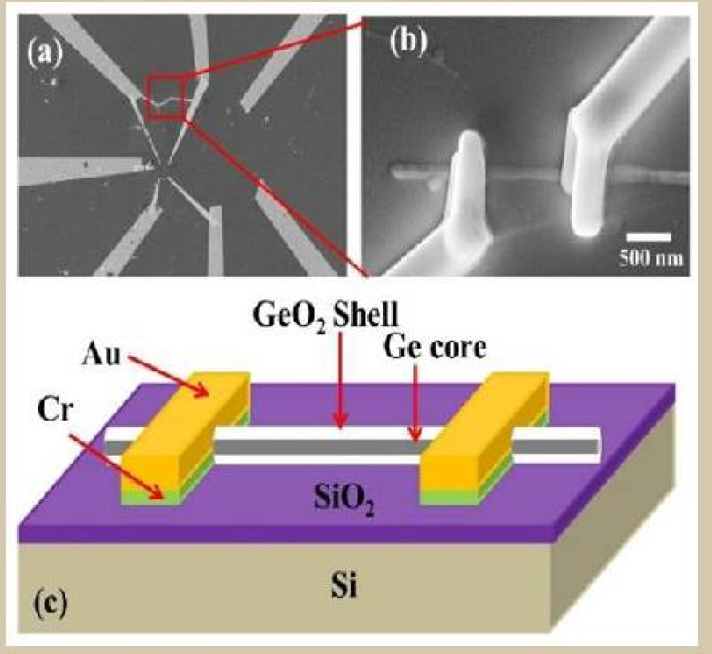
One-dimensional (1-D) semiconductor nanostructures such as nanotubes and nanowires are considered as potential building blocks for the miniaturized electronic, sensing and photonic devices. They exhibit a strongly enhanced photoresponse due to enhanced light trapping and wave-guiding capability inside the cylindrical cavity via total internal reflections from the periphery making attractive for miniaturized photodetectors with high responsivity, faster speed, high signal-to-noise ratio (SNR), and extremely low power consumption. Several researchers at the Centre have been involved in the fabrication of ultra-high responsivity (>10^4 A/W) single nanowire Si and Ge photodetectors using nanoscale lithography techniques, which exhibited polarization sensitive photodetection. Moreover, hybrid nanostructures interconnecting fundamental light-matter interactions of dissimilar components provide an innovative platform for designing futuristic photonic devices like polaritonnanolasers, spin-switches, digital data storage for quantum computing, single photon transistor and metamaterials.Few research activities in this directions are highlighted in following page.

3.2.1 Ultra-high Responsivity Single Nanowire Photodetectors

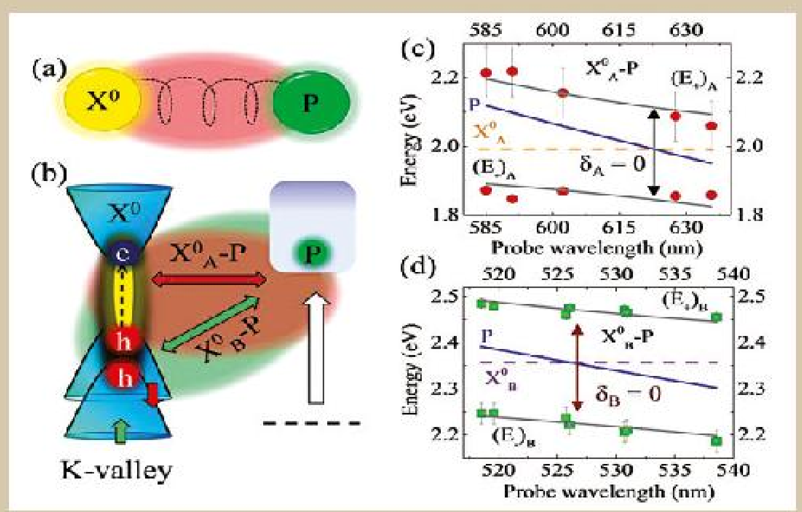
Recently, the research group has demonstrated broadband and visible-wavelength meta-semiconductor-metal (MSM) photodetector using single nanowire core-shell (Ge- GeO_2) heterostructures. The fabricated self-powered detectors[1] have been found to exhibit polarization sensitive response to a broadband spectrum from 350 to 900 nm with a peak responsivity (~0.6×10^4 A/W) and detectivity (~3.8×10^{12} Jones).

3.2.2 Bright Exciton-Plasmon Polaritons in Size-Tunable Metal-WS_2 Hybrid Nanostructures

Strong light-matter interactions between resonantly coupled metal plasmons and spin-orbit coupled bright excitons were studied from two dimensional (2D) transition metal dichalcogenides (TMDs), which can produce discrete bright exciton-plasmonpolaritons (plexcitons). Here, both the bright plexcitons are identified discretely at room temperature and their ultrafast temporal dynamics in size-tunable Au-WS_2 hybrid nanostructures are investigated using a helicity-controlled femtosecond pump-probe spectroscopy technique. The Rabi-splitting energy is as high as ~250 meV for both the plexcitons, validating the strong-coupling conditions of polariton formation[2]. Realization of these novel bright exciton-plasmon interactions in the metal-TMDs platform is, therefore, interesting for both fundamental understanding and their possible futuristic applications in quantum photonics operating at room temperature.



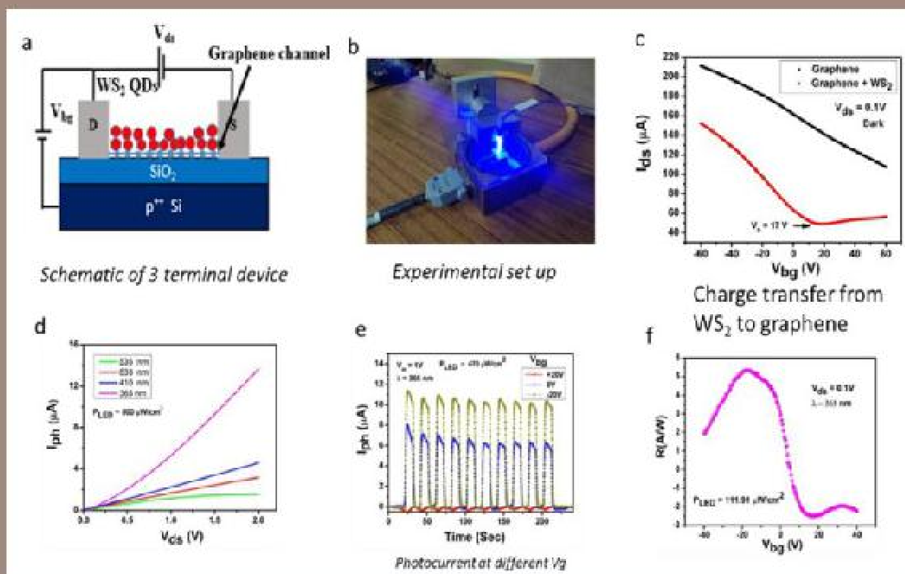
(a) & (b) SEM micrographs and (c) schematic of fabricated single nanowire photodetector device



Schematic representation of (a) plexcitonwith theexciton (X) and plasmon (P) coupled together through a hypothetical spring. (b) exciton-plasmon coupling in metal-WS_2 hybrid nanostructures (c) & (d) anti-crossing behavior of energy branches (E+ and E_) for individual bright polaritons

3.2.3 Optoelectronics with all van der Waal heterostructure

A significant drawback with these 2D layered materials is the low absorption of incident light, limiting the device in terms of both performance and efficiency. The researchers in this center has created a three terminal, large scale, broadband (UV to IR) photo detector by incorporating an optically active layer of TMDC (WSe2 quantum dots) on centimeter scale graphene prepared by CVD method (described in the Figure).



(a) Optoelectronic transport measurement set up, (b) I-V characteristics at different gate voltages for a two terminal few layer MoS2 transistor. Inset shows the device image. (e) I_{DS}-V_{bg} characteristics in dark and, in presence of red light, showing signal

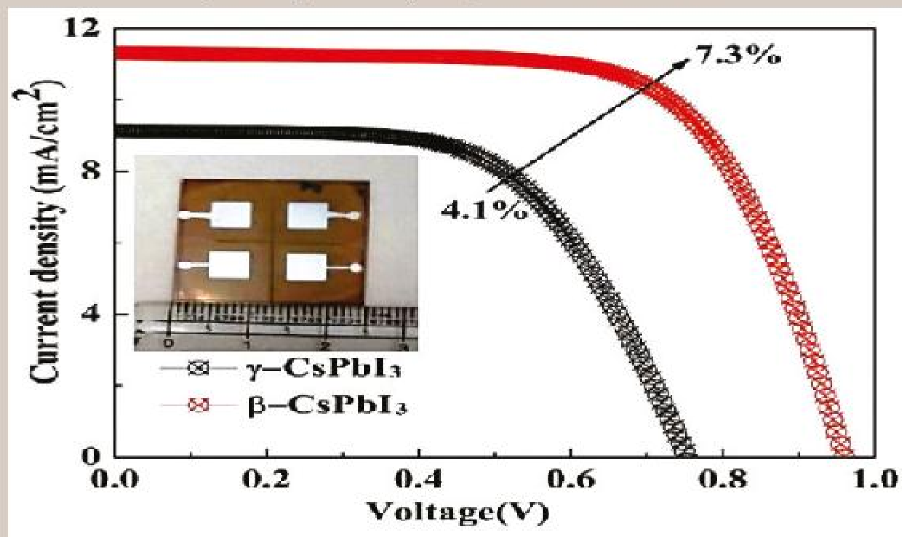
Ultra low temperature cryostat

Helium Liquefier

Advanced functional materials for energy harvesting and sensing

The impending problems associated with our dependence on fossil fuels has driven the search for alternate energy sources. In this section we will discuss work being carried out in the centre on alternate materials for use in energy harvesting and sensing.

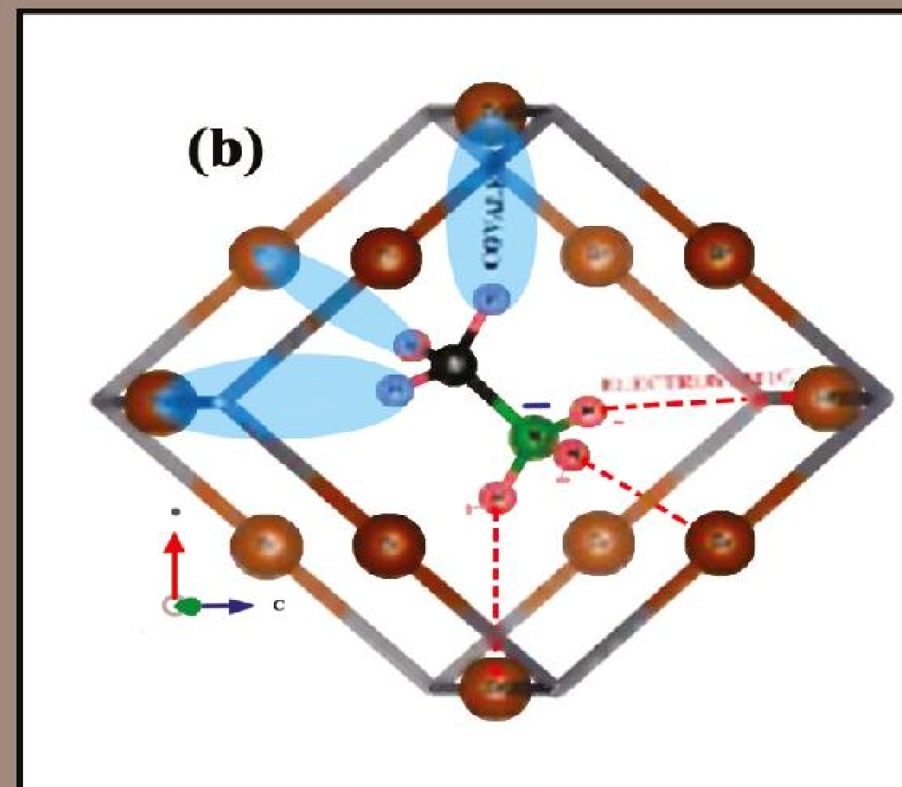
Improving stability of perovskite solar cells:



- The rapid increase in the efficiency of solar cells involving perovskites has seen them becoming the new rising stars of PV technology.
- A problem plaguing the widespread use of perovskite solar cells has been the stability of these materials in ambient conditions.
- Scientists from S.N. Bose centre have recently synthesised a new phase in β-CsPbI3 in its one dimensional form. This is found to have excellent photostability under humid conditions.
- The fabricated PV devices with inverted p-i-n configuration of ITO/PEDOT:PSS/CsPbI3/C60/BCP/Al structure show a significant enhancement in fill factor from 59.6% to 67.2% and 78% enhancement in efficiency for β-CsPbI3, in comparison to conventional β-CsPbI3 phase.
- The efficiency of the air-stable device employing ?-CsPbI3 nanorods of inverted perovskite solar cells [1] is found to be moderately high ~ 7.3% without any use of glovebox or encapsulation.

Theoretical insights into the perovskites:

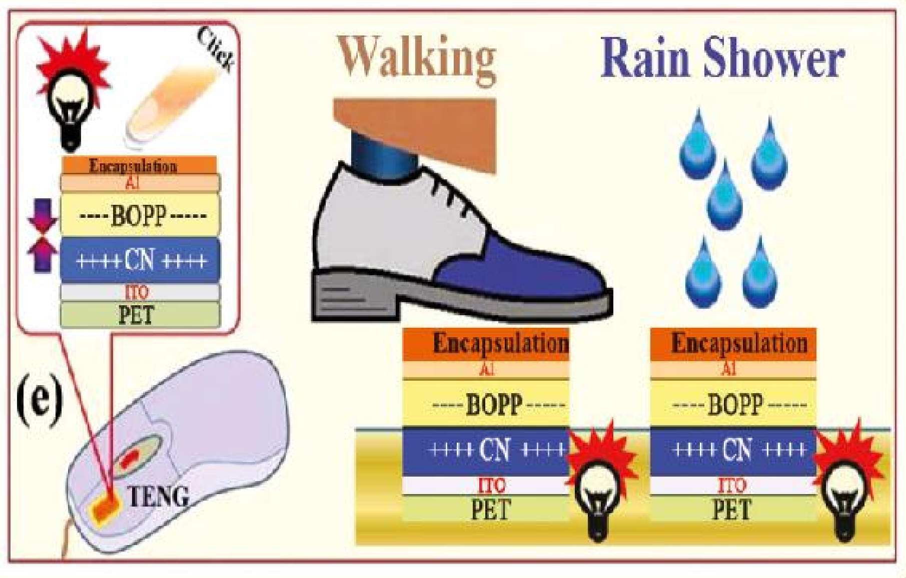
- Key aspects of the use of any material for photovoltaics involve having a suitable band gap to tap a portion of the solar spectrum and to efficiently separate the generated electron and hole pair before they recombine.
- Considering hybrid perovskites of the form ABX3, where A is a molecule, scientists of the centre have shown that the atom at the A site in these materials determines the structural distortions of the inorganic B-X network and thereby the band gap [2].



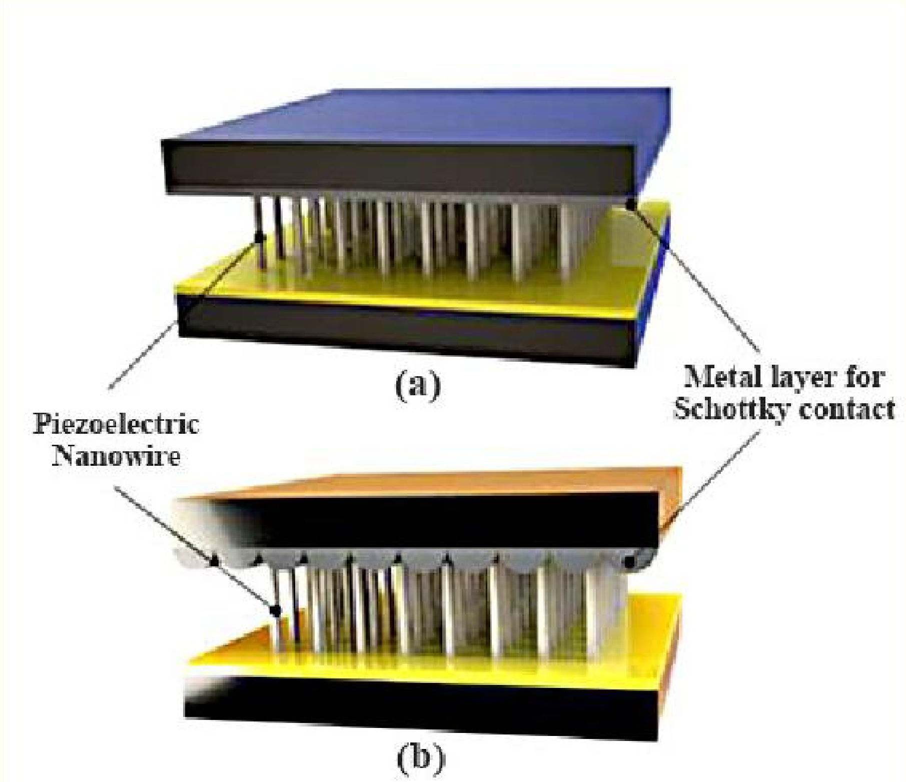
- The nature of interactions of the molecule at the A site is through hydrogen bonding. Scientists of the centre have considered methyl ammonium (MA) at the A site and have shown that the interactions could have a covalent part as well as an electrostatic part, which also results in the molecule moving away from the centre of the inorganic cage [3].

Portable energy sources:

- Triboelectric nanogenerators (TENG) working on the principle of contact electrification are useful to scavenge energy from the surroundings especially from human motion or actions.
- Scientists at the Centre have demonstrated flexible and light weight TENG devices [3] consisting of two-dimensional (2D) graphitic phase of carbon nitride (g-C3N4) in the form of nanosheets which are suitable as they have good thermal stability (as high as 600 oC) and chemical resistance.
- The fabricated TENG devices2 can drive multiple LEDs, efficiently charge a capacitor to as high as 55 V on repeated biomechanical imparting and are found to be extremely sensitive to routine human activities like walking, water showering or using as a writing/drawing pad.



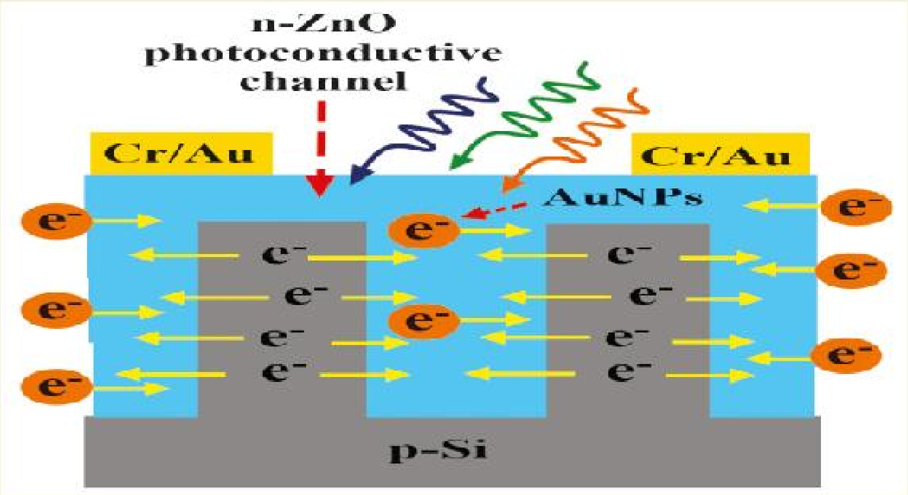
Schematic of 2D g-C_3N_4
TENG based mechanical energy harvesting
using human activities and rain shower etc.



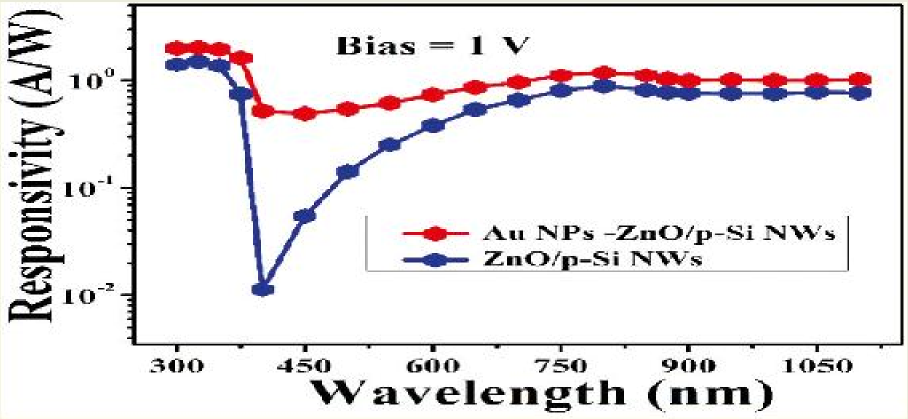
Schematic of Schottky contact for piezoelectric nanowires

- An alternate route to power generation is through a piezoelectric nanogenerator (PENG).
- An attempt was made to design a robust, scalable, and cost-effective piezoelectric nanogenerator based on the a polymer PVDF and BaTiO3 nanocomposite.
- The piezoelectric nanogenerator with BTO-PVDF composite gives an electrical output of voltage 1.5 V and power output of 1 μW.
- Low-power electronics are powered by charging a 10 μF capacitor using the PENG device.

Broadband photodetector:



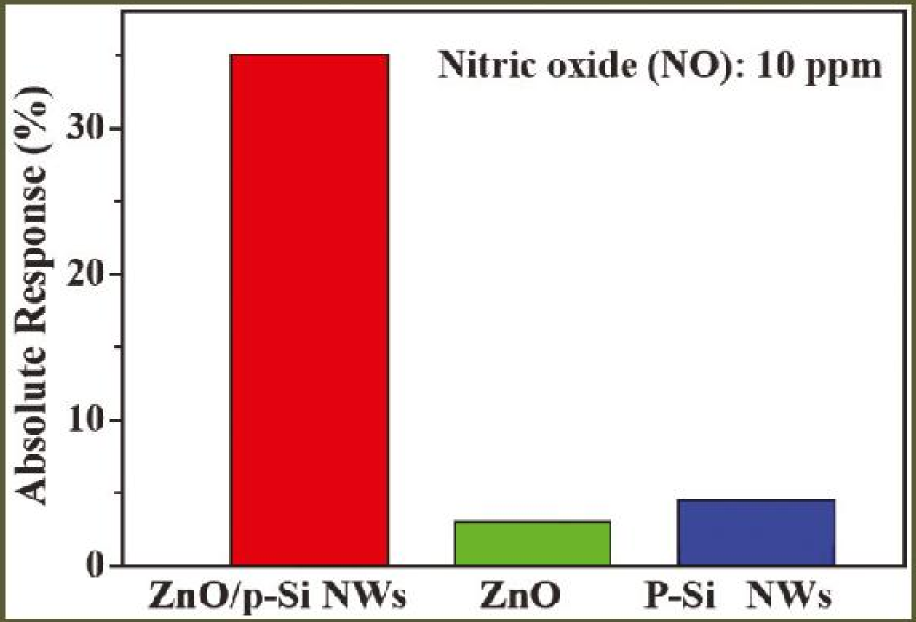
A schematic illustration of photo-gated device where the n-ZnO channel receives carriers from the core of Si NWs as well as Au NPs when they are illuminated



Spectral responsivity (R) of ZnO/p-Si NWs core shell arrays with Au NPs and without Au NPs under different wavelength

- The basic principle used is that the photo generated carriers created in materials with different band gaps are transferred to the conduction band of the photo-detector material. This helps to extend the response of a photo detector beyond its fundamental band-gap and gives a detector that works over an extended range from UV to NIR (300-1100) [5].

Gas sensing applications:



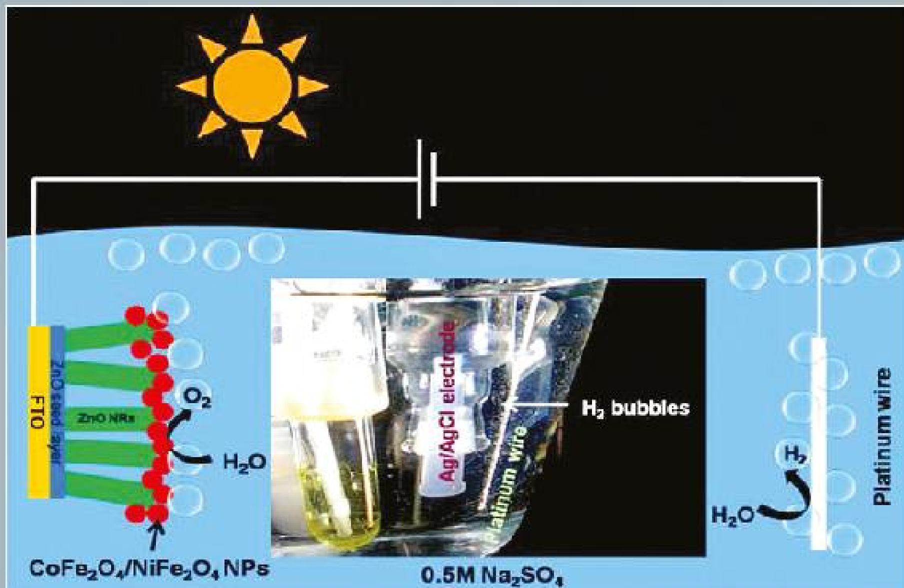
Comparison of absolute gas sensing response of ZnO/p-Si NWs, ZnO and p-Si NWs arrays to 10 ppm of NO gas at room temperature.

- The tuning of charge carriers in the above heterojunction array of ZnO/Si NWs was also done by gas injection in the device [6].
- This allows it to be utilised as an ultra high sensitive gas sensor with noise limited detectivity approaching 10 ppb by gas injection in addition to exhibiting very high selectivity towards nitric oxide (NO) gas operating at room temperature.

References:

1. Advanced Energy Materials, 2020, 2001305 (DOI: 10.1002/aenm.202001305).
2. J. Phys. Chem. Lett. 7 3270 (2016).
3. Phys. Rev. B. 95, 214118 (2017).
4. Nanoscale, 2020, 12, 21334
5. J. Phys. Chem. C 124 , 22235-22243 (2020).
6. Nanotechnology 30, 305501 (2019).

Next generation fuel: Hydrogen



The global population demands 15 TW of energy (2011) per day, to maintain the basic standard of modern-day life. Most of it comes from fossil fuels such as coal, oil, natural gas, etc which are having limited resources. Burning of fossil fuels also emits greenhouse gas, causes global warming and environmental degradation. To tackle the challenge of future energy demand in a clean, green, and environmentally friendly way, sustainable development of renewable energy technologies is necessary. Among various form of renewable energy resources, such as wind energy, water energy solar energy, the last one is considered to be the ultimate solution to the global energy challenges. Solar energy can be converted to electrical energy by different kinds of solar cells. However, it is still a challenging task to store electric energy efficiently and deliver it when the sun is not present. Hydrogen gas (H2) can be a suitable replacement for fossil fuels and can be obtained by splitting water into hydrogen and oxygen using solar energy, first discovered by Fujishima and Honda using TiO2 as photocatalyst. H2 has a high energy density associated with zero carbon emission and is suitable for the development of a sustainable environment.

There are several ways to get H2 from water such as photocatalytic water splitting, photoelectrochemical (PEC) water splitting and photovoltaic water splitting. Among these methods, PEC water splitting is an emerging field of H2 energy-related research. A PEC cell employs a photoanode/cathode (a semiconductor), a reference electrode, and a counter electrode (novel metal) to split water into H2 and O2. The very first step of solar water splitting is to capture the solar energy in the semiconductor photoelectrode surface. There are several criteria of a semiconductor to be used as photoelectrodes such as; Bandgap of material should be such that it can absorb broad visible spectra of solar light, lower charge carrier recombination, high mobility of majority carrier and longer minority carrier diffusion length means better charge transportation and good stability of the material in an aqueous environment. Apart from that, the position of conduction and valance band of the material should be suitable with respect to water oxidation and reduction potential. After the Fig.1:photoelectrochemical (PEC) water splitting

discovery of water splitting in TiO2 a number of semiconductor materials such as ZnO, WO3, BiVO4, Cu2O, CuBi2O4, etc have emerged as photoanode/cathode material suitable for PEC cell applications.

In recent years we are working on ZnO-based photoanodes because of its good conductivity, suitable band position, low cost, and easy synthesis methods as shown in Fig.1. However, the moderate stability in aqueous medium and wide bandgap (absorbs UV light of solar spectrum only) of ZnO, limits its application in PEC cell. To overcome these limitations and enhance its photoactivity, different strategies are employed, such as designing of ZnO nanostructure-based photoanode to facilitate the charge transportation, elemental doping which tune the bandgap and enhance the conductivity, hetero-architecture development between ZnO and a visible light active narrow bandgap material which efficiently increase the overall absorbance and charge separation and plasmonic nano-particles deposition to improve the optical absorbance. In our recent work, we have fabricated CoFe2O4 and NiFe2O4 nanoparticle (NPs) anchored ZnO nanorods (NRs) photoanodes. Both CoFe2O4 and NiFe2O4 is having a lower bandgap which can harvest the broadband solar spectrum efficiently and high chemical stability during water splitting reactions. The formation of n-n/p-n, type -II heterojunction improve rapid photocarrier separation and reduced electron-hole pair recombination leading to enhanced photocurrent density and applied bias photon-to-current efficiency as high as1.23 mA.cm-2 at 1.23V vs. RHE and 0.32% for the ZnO/NiFe2O4 photoanode.

Translational Research Activities under Technical Research Centre (TRC)

Making Us Innovative In The Innovation Space

The Technical Research Centre (TRC), funded by Department of Science & Technology, Ministry of Science & Technology, Government of India at S. N. Bose National Centre for Basic Sciences (SNBNCBS) has been launched on 1st January 2016. The aim was to establish a research centre and create an eco-system for Make in India initiative in the country by harnessing science and technology platforms and leveraging on the existing core strength in materials science and spectroscopic techniques in the Centre. The Centre has so far transferred six technologies to industries, six prototypes are ready for Transfer of Technology, generated Several IPs through 24 national and one international patents, trained manpower (about 50) to cater the future need of the country and revenue generation through national and international consultancy projects / user charges.

Major Target Areas of on-going TRC at SNBNCBS

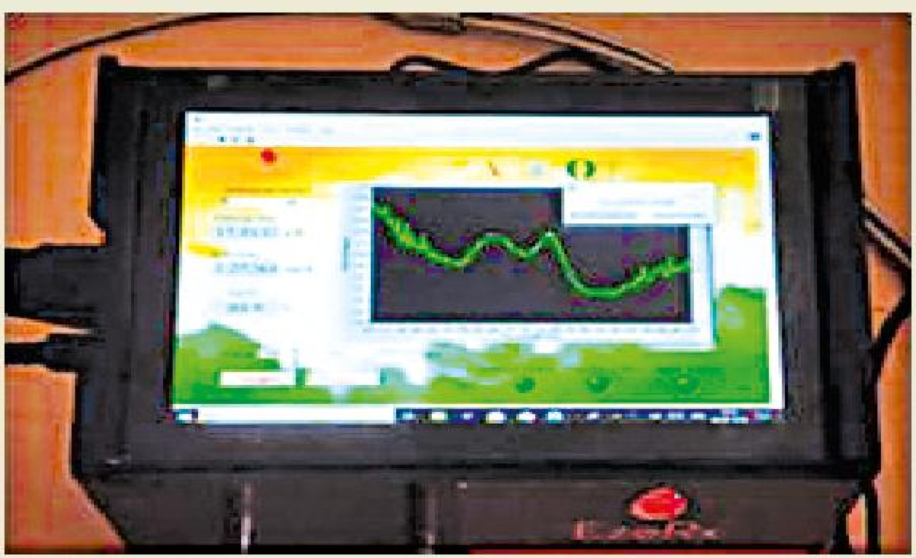
- Health Care: Development of Low-cost Non-Invasive Medical Diagnostics for Capacity Building for maternal/child health care & Ulcer detection.
- Environment: Development of Low-cost Sensors for sustainable management of Water & Air for life on land and life below water.
- Food Security: Development of Low-cost Sensors to provide food security to households.
- Low-Cost Instrumentation: Development of low-cost instrumentation for the industries and to enhance employment opportunity.
- Input through Computation: High-end computation for the development of technologically Important Indigenous Materials of National need.

Transfer of Technologies to various StartUps and Companies

Products (AJO, AJO-NEO, Bosetizer, Boseshield and Breathe-Analyzer) were transferred to industries from the Technical Research Centre of S N Bose National Centre for Basic Sciences.

Developed Prototypes Ready for Transfer of Technology

Development of Non-Contact Optical Device for Clinical Diagnostics of Anaemia, Jaundice and Oxygen Deficiency (AJO Device, अजेययंत्र, অজেয়যন্ত্র at Resource Limited Point of Care Setting



Salient Features

- Development of a non-contact non-invasive easy to use low cost optical device and associated software for measuring haemoglobin, bilirubin and oxygen saturation at point of care and immediate electronic transmission of test results
- Efficient diagnosis of three parameters at one go without touching the subject (non-contact and non-invasive).
- Ability to diagnose in Fragile and Conflict-affected Settings.
- Ability of Immediate delivery of test results through cloud helping in online monitoring and e-health care.
- Compatibility with mobile phone platform for data transceiving for treatment plan.
- Transfer of Technology to M/s EzeRx Health Tech Pvt. Ltd

Non-Invasive Screening for the Neonatal Hyperbilirubinemia (AJO-Neo)

Salient Features

- Measures bilirubin level in neonatal subject in a non-invasive and non-contact way.
- Non-Invasive determination of blood parameters
- Pain less and Accurate
- Instant Results
- No Consumable and Recurring Cost
- Transfer of Technology to M/s Zyna MedTech Pvt. Ltd

An Active Respirator with attached exhalation valve and suspended particulate matter Filter for comfortable and Hygienic Breathing (BoseShield)

Salient Features

- Stop rebreathing of carbon dioxide.
- Control moisture inside the mask
- Provide cool feeling
- Improves the Clarity in Speech of a person with this mask.
- The mask contains specially programmed Battery operated, motorized exhalator.
- Active respirator can be powered by external battery, power bank, USB charging devices, mobile charging stations, electric and solar powered systems.
- Active exhalation pump helps in the evaporation of water droplets and creates cooling effect..
- Portable
- Transfer of Technology to M/s Paulmech Infrastructure Private Limited

Long-Lasting Nano-Sanitiser with a dispensing Antimicrobial Layer (Bosetizer)

Salient Features

- Stop dehydration of hand.
- Provide long-lasting germicidal effect.
- Cures existing skin problem.
- Use of Nanotechnology for effective interaction with residual microbes on the hand.
- Formation of few antimicrobial monolayers for long lasting protection.
- Ozone impregnated organic oil-based substance to achieve antimicrobial action.
- Transfer of Technology to M/s Paulmech Infrastructure Private Limited

Non-invasive detection of ulcer causing Helicobacter pylori infection inhuman stomach using exhaled breath analysis (Breathe-Analyzer)

Salient Features

- A simple diagnostic methodology for detection of Helicobacter pylori infection as well as ulcer disease using human breath analysis.
- It is non-invasive technique without endoscopy and biopsy tests
- It can identify presence of the infection in human stomach by following a simple protocol.
- The system can be used even after the eradication of the infection or standard therapies
- The analyzer can be used for online and off-line breath analysis
- The invention is a new product and better replacement of the existing methodologies
- Transfer of Technology to M/s HPA Instruments, Hyderabad

A Spark Spectrometry Based Point of Care Portable Device for Simultaneous Detection of Na+, Li+ and K+ Concentration in Body Fluid (NaLiK)

Salient Features

- Simultaneous determination of essential electrolytes in human subject
- Minimally invasive detection
- Field Deployable
- No complexity of sample presentation
- Instant results
- Operable by minimally trained person
- Cost - effective
- Prototype is ready for Transfer of Technology

A Spectroscopy Based Fluoride Sensor for Drinking Water (FeFlu)

Salient Features

- Detection of Fluoride level in Drinking Water
- Nano Particle based sensor
- Highly Selective
- Instant Results
- CCD sensor array-based detection
- Prototype is ready for Transfer of Technology

A Spectroscopy-based Optical Device for Estimation of Milk Quality (Mil-Q-Way)

Salient Features

- An optical spectroscopy-based device has been developed to assess the milk quality from different commercial origins and detect milk adulteration even after SNF rebalancing.
- Distinguish different origins of milk
- Able to detect adulterated milk
- Non-invasive detection mode
- Fast online screening
- Two parameter quality assessment of milk
- Low-cost, compact and portable for user friendly
- Prototype is ready for Transfer of Technology

Fabrication of High Surface Area Hybrid Nanocomposites for Carbon Dioxide capture and Detection of COPD Disease (CapNanoScope)

Salient Features

- Our main focus is on the efficient capture and subsequent sequestration of CO_2 from the atmosphere. Additionally, detection of Chronic Obstructive Pulmonary Disease (COPD) is another major goal.
- Porous silica having high specific surface area.
- Large scale synthesis to capture CO_2 emission.
- Heteroatom doping significantly increases CO_2 adsorption capacity.
- Removal of CO_2 from closed environment.
- Detection of COPD disease
- Prototype is ready for Transfer of Technology

A Solid State Visual Ammonia Sensor at Room Temperature (Ammo Watch)

Salient Features

- To make a cost effective easy to use paper based visual ammonia gas sensor with room temperature operation with simple real time colour change based capability for rapid and selective detection of toxic ammonia gas in environment in a disposable manner.
- Highly Sensitive (~10 ppm) and Highly Selective
- Cost Effective Fabrication
- Quick Response (~ 10 sec for 10 ppm NH_3 gas concentration)

Advanced features:

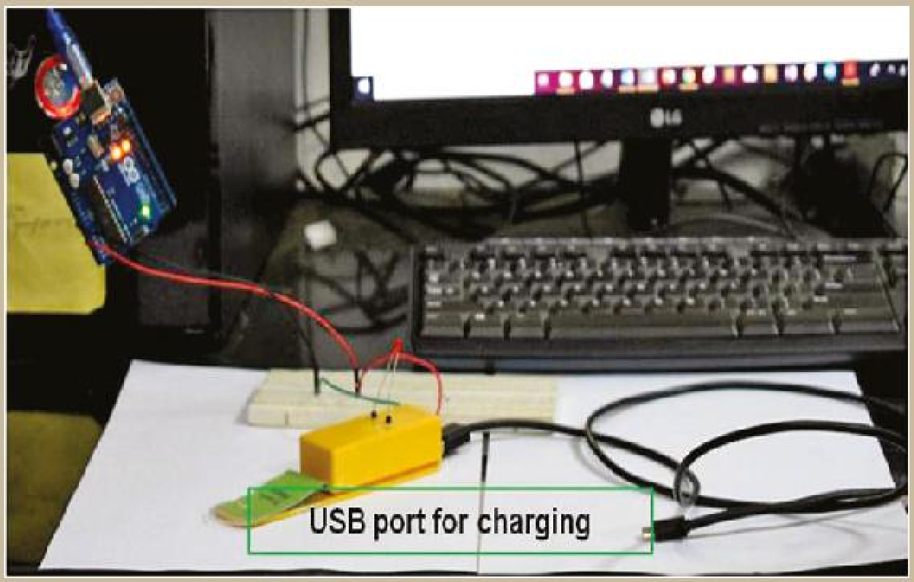
- Paper Based Disposable Technology
- No Electronics/External Energy Source required
- Room Temperature Operation
- No Trainee Personnel needed for using
- Prototype is ready for Transfer of Technology

A paper electronics based solid state ammonia sensor with ultra-high sensitive (sub ppm) detectivity (AmmoRead)

Salient Features

- To fabricate a cost-effective paper electronics based flexible electrical ammonia gas sensor with sub ppm (~ 10 ppb, noise limited) detectivity for selective detection of ammonia gas for exhaled breathe analysis.
- Highly Sensitive (~ 96% for 20 ppm ammonia gas) and highly Selective
- Cost Effective Fabrication
- Very low detection limit (~10 ppb by noise limited detectability)
- Disposable Technology
- Compatible with low power paper electronics
- Room Temperature Operation
- Easy read out with remote access through WiFi and wireless technology.
- Prototype is ready for Transfer of Technology

Piezo-electric nanowires for energy harvesting and sensitive motion (PIEZOcell)



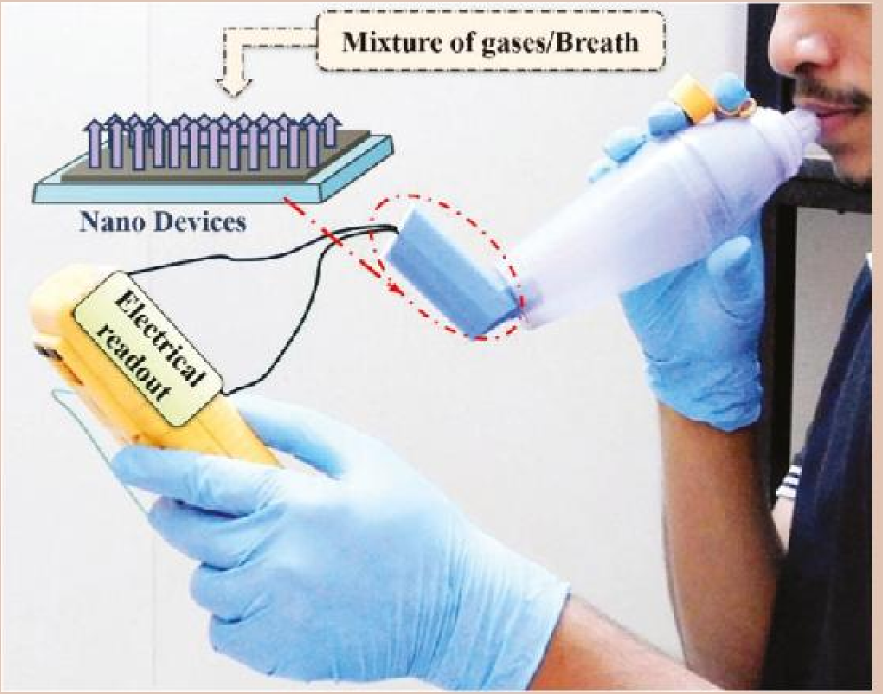
Salient Features

- Small scale portable power generation that can drive microelectronic systems and health care devices without any external power source.

Charging Device:

- Needle tip Nanowires for better mechanical contact
- Tuneable internal resistance~650 K ohm
- Voltage output ~8V, Current output 200μA
- Charging time ~40sec of 10μF/5V capacitor
- Prototype is ready for Transfer of Technology

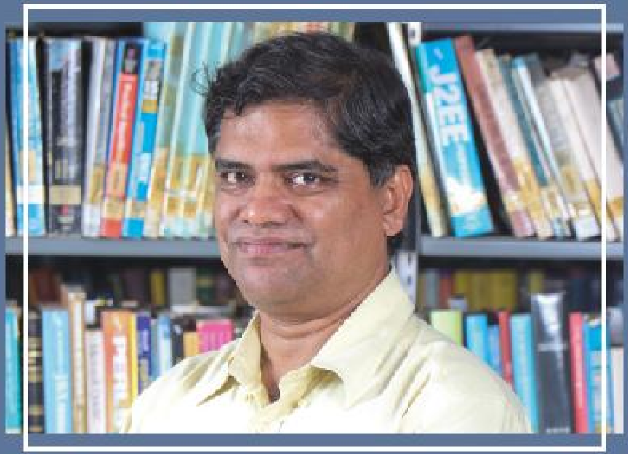
A gas sensing system for selective detection of NO (Nitric Oxide) gas at room temperature (NOsense)



Salient Features

- The present invention is the quick and cheap methods for detection of hazardous gases in work places.
- Low projected cost and easy read out with remote access through WiFi and wireless technology.
- Uses easily available materials and innovative use of new nano-materials.
- Portable readout devices.
- Room temperature operation and low power consumption.
- Good selectivity and high sensitivity (< 1ppm).
- Easy production method and does not need costly capital investment.
- Prototype is ready for Transfer of Technology

FACULTY MEMBERS



Amitabha Lahiri
Senior Professor
Quantum Field Theory, Mathematical Physics, Gravitation

Anjan Barman
Senior Professor
Experimental Condensed Matter Physics

Archan S Majumdar
Senior Professor
Cosmology, Quantum Information Theory

Biswajit Chakraborty
Senior Professor
Quantum Field Theory

Gautam Gangopadhyay
Senior Professor
Chemical Physics

Jaydeb Chakrabarti
Senior Professor
Soft Condensed Matter & Complex Fluids

FACULTY MEMBERS

Kalyan Mandal
Senior Professor
Experimental Condensed Matter Physics

Priya Mahadevan
Senior Professor
Condensed Matter Theory

Ranjit Biswas
Senior Professor
Physical Chemistry

Samir Kumar Pal
Senior Professor
Ultrafast Spectroscopy of Molecules and Nanomaterials,
Biomedical Instrumentation

Samit K Ray
Senior Professor & Director
Experimental Condensed Matter Physics

Tanusri Saha-Dasgupta
Senior Professor
The Physics of Materials

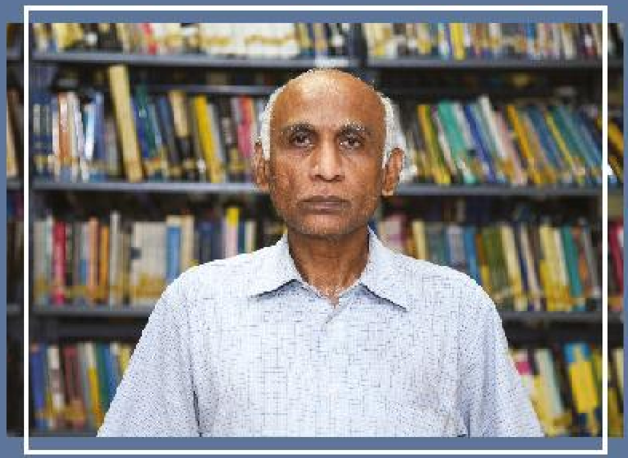
FACULTY MEMBERS

Manu Mathur
Professor
Quantum Field Theory

Prosenjit Singha Deo
Professor
Mesoscopic Systems

Rajib Kr. Mitra
Professor
Experimental Biophysical Chemistry

Soumen Mondal
Professor
Observational Astronomy & Instrumentation



M. Sanjay Kumar
Associate Professor
Quantum Optics

Manik Pradhan
Associate Professor
Laser Spectroscopy, Biomedical Optics

FACULTY MEMBERS

Manoranjan Kumar
Associate Professor
Condensed Matter Theory

Punyabrata Pradhan
Associate Professor
Nonequilibrium Statistical Physics

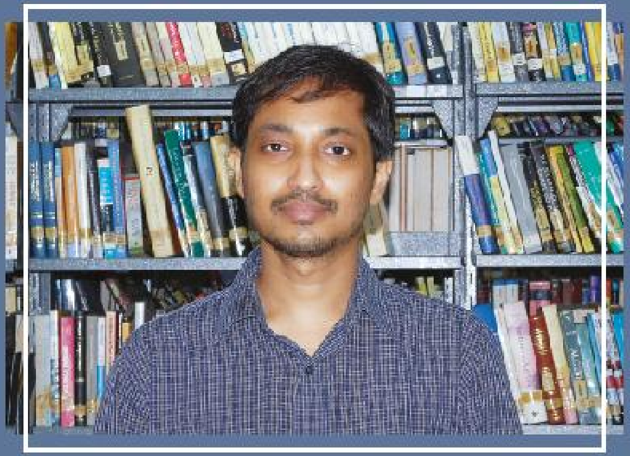
Ramkrishna Das
Associate Professor
NOVA and Variable Star

Sakuntala Chatterjee
Associate Professor
Statistical Physics, Biological Physics

Sunandan Gangopadhyay
Associate Professor
Theoretical Physics

Abhijit Chowdhury
Assistant Professor

FACULTY MEMBERS



Atindra Nath Pal
Assistant Professor
Experimental Condensed Matter Physics

Nitesh Kumar
Assistant Professor
Material Science

Suman Chakrabarty
Assistant Professor
Theoretical & Computational Chemistry

Tapas Baug
Assistant Professor
Observational Astronomy

Thirupathaiah Setti
Assistant Professor
Experimental Condensed Matter Physics

Urna Basu
Assistant Professor
Non equilibrium statistical physics

SCIENTISTS

Barnali Ghosh (Saha)
Scientist F
Experimental Condensed Matter Physics

Sanjay Choudhury
Scientist D
In-charge, Computer Services Cell

ADMINISTRATIVE OFFICERS

Shohini Majumder
Registrar

Saumen Adhikari
Librarian-cum-
Information Officer

Nibedita Konar
Deputy Registrar
(Academic)

Debashish Bhattacharjee
Deputy Registrar
(Administration)

Suman Saha
Deputy Registrar (Finance)

Mithilesh Kumar Pande
Campus Engineer-cum-
Estate Officer

Santosh Kumar Singh
Assistant Registrar
(Purchase)

Administrative and Technical Staff Members of the Centre

REMINISCENCES

It is a great pleasure to congratulate the S.N. Bose Institute on the upcoming anniversary of its founding department the DST. I recall with pleasure my various visits to the Institute over the years and my interactions and activities there, which include inter alia a modest contribution to improving the garden. I am impressed with the way in which in recent years the activities have branched out to include research on problems of immediate social relevance, and hope that it is coping well with the present very difficult circumstances. My very best wishes for the next half-century.

Anthony James Leggett
Nobel Laureate (2003),
University of Illinois (Distinguished Visitor)

It has been my pleasure to visit the S N Bose Institute several times. I remember with particular affection the visit in 2012. On that occasion, I delivered the C K Majumdar Memorial Lecture: 'Making light of mathematics', and participated in the Conference on Statistical Physics and Nonlinear Dynamics…..",

I enjoyed many conversations with members of the institute and conference participants, especially with Professor Partha Guha, who has since been extensively developing another aspect of my research with Professor Shukla, on curl forces.

Michael Berry
University of Bristol (Distinguished Visitor)

The strong efforts at the S. N. Bose National Centre for Basic Sciences in the field of electronic structure and theory of the solid state, makes the institute stand out in the world. I am happy to recollect the memorandum of understanding that was signed between the Centre and the Department of Physics, Uppsala University. Sincere, best wishes on the occasion of the Golden Jubilee celebration.

Olle Eriksson
Uppsala University (Collaborator)

"...We have been lucky to live in times of growing globalization and where institutions like the DST and the MPG existed to support basic science for the benefit of everyone. Let us hope it will stay like that."

Ole Krogh Andersen
MPI Stuttgart (Collaborator)

"…..It has been a memorable experience for me to remain actively associated with the Centre for a period of five years as the Chairman of Governing Body and Chairman, National Advisory Committee of a new DST initiative on TRC project on translational research. S.N.Bose Centre is small in terms of its faculty strength, about thirty or so, but the coverage of scientific areas by its faculty is fairly wide. In the Governing body we decided that apart from our regular functions as listed in the agenda of our meetings, we would spend time with the research groups- students and faculty included, to get to know their work in some details. Capturing the scientific excitements from the students and the faculty has indeed enriched us immensely.

Witnessing the progress of the TRC project has been a unique experience.It has been a very gratifying experience to observe at the end of the five-year period that a number of the projects taken up under TRC could deliver marketable products and earn some revenue. On the whole my association with the Centre has been very rewarding. The personal relationship I developed with the students, members of the faculty and the administrative staff will always remain in my pleasant memory".

Srikumar Banerjee
Homi Bhabha National Institute,
Ex-Chairman, Governing Body, SNBNCBS

"Professor Chanchal Kumar Majumdar, the Founder Director of the SNBNCBS, came back to India from the US and joined the TIFR in 1966….. We continued to be in very close contact over the years. In 1987 Chanchal was invited to be the Founder Director of the SNBNCBS, a position he occupied till he retired in 1999. My close connections with the new Centre covered the formative years when he faced more than a fair share of problems in dealing with people, some staff and faculty included. I was witness to these hardships, and in retrospect I feel glad that to some extent I was able to help him in his work as Director. It is a tragedy that in 2000, soon after retirement, he passed away.

N. Mukunda
IISc (Former Governing Body member & ex-Chairman, ARPAC)

"Amongst the many initiatives taken by the DST over the past 50 years, one that has paid rich dividends is the establishment of the S. N. Bose National Centre for Basic Sciences. …. I have been fortunate to have had a chance to visit SNBNCBS since early days, in various capacities. ……. I was also involved with some aspects of governance, as a member of the Governing Board of the Centre for several years…... These visits and interactions have given me a chance to see the Centre grow, both in terms of infrastructure and, more importantly, people. As in any institution, it is the latter which matters most, which is why I am confident that the Centre has a great future ahead of it"

Mustansir Barma
DAE (Former Governing Body member)

"…. My association with the physicists of the S N Bose Centre has been very strong both at the scientific and social level. Particular mention may be made of Prof Chanchal Majumdar, Prof Abhijit Mookerjee and Prof Sushanta Dattagupta and their groups. In later years I have close scientific collaboration with Prof Ranjan Chaudhury. …. Particularly in last two decades I have been visiting Bose Centre almost annually as an International Visitor under their VASP program. …. Finally I wish to say that S N Bose Centre has become a great place for both basic and applied research…."

Mukunda P Das,
The Australian National University (VASP Visitor)

"Since its launch in 2004, TWAS-S.N. Bose Fellowship Programme for PhD and postdoctoral researchers has helped advance important, early physics careers in the global South. Held through our valued partners at the S.N. Bose National Centre for Basic Sciences in Kolkata, India, the programme's graduates have achieved both accomplishments and prestige. Awardees have come from Algeria, Bangladesh, Cameroon, Ethiopia, Nepal and Nigeria…….TWAS is proud of this fruitful collaboration. Physics and the basic sciences are the bedrock of scientific capacity, providing the foundation on which the applied sciences and science education can stand. We anticipate that India's historical leadership in the physical sciences will continue to play an important part in the flourishing of science throughout the developing world for many more years to come"

Romain Murenzi
Executive Director, TWAS

REMINISCENCES

EX-FACULTY MEMBERS

"During my tenure (Feb 1999 - Mar 2005) the focus was on (i) developing infrastructure, including a state-of-the art library, a computer centre and campus landscaping, given the Centre's emphasis on a Visitors' programme, (ii) forming an interdisciplinary condensed matter group encompassing Electronic Structure, Soft Matter, Mesoscopics and Quantum Optics - in both theory and experiments, (iii) initiating a (post-B. Sc.) Ph.D. curriculum, in which students were encouraged to carry out need-based research in neighbouring institutes, in order to properly utilize complementary resources and (iv) activating Memorial Lectures and Colloquia"

Sushanta Dattagupta
(Director, SNBNCBS, 1999 - 2005)

"DST and the autonomous institutions nourished by it, provided the much needed competitive edge to basic science research in the country. I got my first project when DST just entered its teen. Still counting on it"

Arup Kumar Raychaudhury
(Director, SNBNCBS, 2007- 2014)

"From a 2-storied building with a small core faculty and a character similar to that of ICTP Trieste, the Centre has grown into a fairly large institution. I was lucky to have been given the opportunity to play a role in its initial stages to coordinate with many other institutions in India and abroad to organize seminars, workshops and conferences. The most memorable event was the Bose Centenary in 1994 when the Centre had the privilege to host one of the largest gatherings of 'who's who' in international physics."… I wish the Centre a very bright future, true to its original charter and befitting the name of Professor Satyendranath Bose"

Partha Ghose
(Former Faculty member & Academic Programme Coordinator)

"While I was formally a member of the S N Bose staff from January 2008 to April2012, my association with it started in 2001 when the then Director , Prof S Dattagupta, started a very ambitious program of joint MSc (4 semesters) followed byPhD (degrees to be given by the then fledgling West Bengal State University)with the teaching at the master's level open to all scientists in Kolkata. This was a unique experiment for our city at that time and I was fortunate enough to be a part of it from its inception and in the process being able to mentor a few outstanding PhD students.…."

Jayanta Kumar Bhattacharjee
(Former Faculty member & Dean)

"I was perhaps the first academic person to join the Centre. The Centre was operational from two rented buildings at Salt Lake. Incidentally the broker who arranged for these buildings was very upset with Prof. Chanchal Majumdar, since he did not get his promised commission as that was not possible. There was no library nor any computers. Despite this, we had good visitors with interesting talks. Surprisingly, there was always a packed audience at our makeshift `lecture hall'. The credit for this was totally due to Prof. Majumdar….. I think this tradition has persisted.."

Rabin Banerjee
(Emeritus Professor, SNBNCBS)

REMINISCENCES
ALUMNI

"... I had been there for my Ph.D. in 1997 August to 2000 October. I must admit that the central attraction of mine to join there was Prof. Sandip K. Chakrabarti, my Ph.D. advisor, what prompted me to leave other Institutes' offers..... Overall, I personally found a very amicable atmosphere during those days in SNBNCBS... . From then, now SNBNCBS has grown a lot and has found its place among one of the best DST supported Institutes in the country, and I am very glad for the same. I look forward visiting there"

Banibrata Mukhopadhyay
IISc.

"My Ph.D. days in S.N. Bose National Center for Basic Sciences have been amazing and memorable during 1994 to 1999. My Ph.D. advisor Late Prof. Abhijit Mookerjee and the founder director of the center, Late Prof. Chanchal Majumdar have influenced me in numerous aspects of life, both academically and non-academically. As I was one of the earlier students who have seen the growth of the present campus since the beginning, I consider myself as one of the lucky co-travelers in this incredible journey, which has taught me rigor in scientific research, ethics, perseverance and tolerance. I am very glad to see the recognitions those my alma mater is receiving and I wish very much a bigger and longer success story of the center in times to come".

Biplab Sanyal
Uppsala University

"......I am very proud to write while the centre in its early days lacked the ambience of a big research/academic institute, it encouraged a new concept of learning, from numerous visitors around the world who visited the centre regularly, organizing state of the art conferences (that were very rare in early nineties), encouraging academic visits by graduate students both in India and abroad. This indeed helped me immensely as a graduate student and played a very important role in my future academic career.

Indra Dasgupta
IACS

"My memories of S. N. Bose Centre dates back to 1990 when I started my PhD career under the supervision of Prof. Abhijit Mookerjee. The Centre then was housed in a rented building with two floors in DB-17. There was scarcity of resources, running a minimal library facility and computational facility. However, we took it as a challenge which I suppose made us prepared for the struggle as researcher in future life. In spite of scarcity of resources, we were fortunate to come across great personalities like Profs. Chanchal Majumdar, Abhijit Mookerjee and Partha Ghosh. The training of those days made me what I am today.

Tanusri Saha Dasgupta
SNBNCBS

S.N. Bose National Centre for Basic Sciences

An Autonomous Institute under Department of Science & Technology, Government of India

JD Block, Sector III, Salt Lake, Kolkata-700 106

www.bose.res.in