



ICONS
2023



IRCC conferences on emerging concepts – ICONS 2023

IITB Workshop on Quantum Science & Technology (QST), February 17–18, 2023

Industrial Research and Consultancy Centre (IRCC)

Centre of Excellence in Quantum Information, Computing, Science and Technology (QuICST)

Indian Institute of Technology Bombay (IITB), Mumbai

SUMMARY REPORT

The Industrial Research and Consultancy Centre (IRCC), along with the Centre of Excellence in Quantum Information, Computing, Science and Technology (QuICST) at Indian Institute of Technology Bombay (IIT Bombay), organised a workshop in the area of Quantum Science and Technology on 17-18 February 2023. The workshop was the fourth in the series of annual IRCC conferences on emerging concepts (ICONS), and was held at the Prof. B. Nag Auditorium, Victor Menezes Convention Centre (VMCC), IIT Bombay.

The main workshop included talks by luminaries of the quantum information and computing world, including Prof. John Martinis (University of California, Santa Barbara and Google Quantum AI Lab.) and Prof. Sougato Bose (University College London), along with eminent figures such as the ex-Principal Scientific Advisor to the Government of India, Prof. K. VijayRaghavan (National Centre for Biological Sciences, Bengaluru). The workshop also featured a distinguished institute lecture by Prof. Serge Haroche, the winner of the 2012 Nobel Prize in Physics for his "ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems." This event was organised on 17 February 2023 in cooperation with CEPIFRA and the French Embassy in India. The two-day event also featured colloquiums and talks by faculty members affiliated to QuICST from different departments at IIT Bombay, covering different aspects of quantum science and technology such as quantum computing and simulation, quantum communication, quantum sensing, cryptography and quantum materials. The event also included a panel discussion by eminent scientists, government officials and industry representatives to deliberate on the emerging quantum ecosystem in India. The workshop was attended by nearly 250 participants, including students and faculty members from both IIT Bombay and other institutes and colleges in the region.

The conveners of the workshop were Prof. Suddhasatta Mahapatra (Physics, PIC QuICST, IIT Bombay), Prof. Siddhartha Santra (Physics, IIT Bombay) and Prof. Kasturi Saha (Electrical Engineering, IIT Bombay).

Key figures for distinguished lecture, keynote address, plenary talk and panel discussion:

- Distinguished Institute Lecture: Quantum Science with Rydberg Atoms
Serge Haroche, *Collège de France, Paris*
- Keynote address: Quantum supremacy using a programmable superconducting processor
John Martinis, *University of California Santa Barbara*
- Plenary talk: Landscape of Quantum Science and Technology
K. VijayRaghavan, *National Centre for Biological Sciences, Bengaluru*
- Plenary talk: Testing Quantum Nature of Gravity
Sougato Bose, *University College London*
- Panel discussion: Quantum Technology - Now and Future
Serge Haroche, *Collège de France, Paris*
Arindam Ghosh, *Professor, Indian Institute of Science, Bengaluru*
R. Vijayaraghavan, *Assoc. Professor, Tata Institute of Fundamental Research, Mumbai*
Manoj Nambiar, *Tata Consultancy Services*
Abdul Kayum, *Deputy Director General, Dept. of Telecommunications, Govt. of India*



Prof. Serge Haroche
Nobel Laureate in Physics (2012)
Collège de France, Paris



Prof. John M. Martinis
University of California, Santa
Barbara



Dr. K. VijayRaghavan
Ex-PSA & National Centre for
Biological Sciences



Prof. Sougato Bose
University College London

DAY 1:

Session 1 – Chaired by Prof. Kasturi Saha

Welcome address and workshop agenda – The event was inaugurated by the Dean, Research and Development, **Prof. Milind Atrey**, with a welcome address and a brief talk about the agenda of the workshop. The Dean highlighted the role of IIT Bombay and IRCC in promoting and highlighting emerging fields and disciplines. This was the fourth annual workshop facilitated by IRCC as part of ICONS series to promote internal networking as well as connection to relevant external players in industry, government R&D organisations and academia. The ICONS series has so far conducted workshops in Artificial Intelligence-Machine Learning in 2020, Sensors in 2021, and e-mobility in 2022. The present workshop focuses on

the emerging area of quantum science and technology, which is expected to play a key role in communication and computation capabilities of the future, as also highlighted by the newly launched National Mission on Quantum Technologies and Applications.

Keynote address on Quantum supremacy using a programmable superconducting processor –

After the welcome address, the technical session was launched with a keynote address by **Prof. John Martinis**, University of California, Santa Barbara. The talk highlighted the promise of quantum computers, in which certain computation might be performed at an exponentially faster rate than on any classical computer. After a brief introduction to quantum bits (qubits) and quantum computation, the speaker highlighted the use of a programmable superconducting processor using 53 qubits. For a simple algorithm, the Sycamore processor by Google would take about 200 seconds to run a quantum circuit a million times, which would take approximately 10,000 years for the best classical supercomputer. This dramatic increase in performance when compared to all known classical machines and algorithms heralds a new and much-anticipated computing paradigm.

Introduction to CoE-QulCST – Prof. Siddhasatta Mahapatra (Physics, IIT Bombay), in his role as the Professor-in-Charge (PIC), provided us with an overview of the newly established Centre of Excellence in Quantum Information, Computing, Science and Technology (QulCST). The centre was established in August 2022, and now has more than 15 associated faculty members with projects worth INR 30 Crores, and state-of-the-art fabrication and measurement infrastructure. The centre partners different government agencies such as DST, MeitY and DRDO, and is closely associated with charting the roadmap for the National Mission on Quantum Technologies and Applications. The PIC noted that the primary spokes of the Centre are Research, Teaching and Outreach, and highlighted the various programmes that have been run or are in the pipeline in each of these areas. The talk provided an overview of the research being conducted by associated faculties in the key areas of quantum computation, communication, sensing and materials, and ended with a peek into the various research facilities and a general vision towards future development and growth of the Centre.



Colloquium on Quantum Computing, Simulation and Machine Learning – The next speaker was **Prof. Sai Vinjanampathy** (Physics, IIT Bombay), who presented a two-part colloquium. The first part reviewed the fundamental principles and recent advances in the broad areas of quantum computing, quantum simulations and quantum machine learning. Basic algorithms such as the Shor's algorithm and the Grover's search algorithms were presented in a modern context, in relation to the quantum singular value decomposition algorithm. The first part of the talk emphasised the application of these ideas in diverse and disparate areas of science and economics. The second part of the talk briefed the audience on some examples of how these broad research themes are applied to various areas of research by the speakers group. Hardware solutions at the intersection of quantum computing and quantum optics with applications to quantum machine learning were presented. The work on quantum sensors which shows the enhancement of the success probability of obtaining the quantum weak value by using non-linear Hamiltonians was presented. Likewise, an implementable quantum dot quantum engine whose output is not mechanical work but instead a reliable entanglement source was presented.

Plenary Talk on Landscape of Quantum Science and Technology – **Prof. K. VijayRaghavan** (NBCS, Bengaluru), former Principal Scientific Advisor to the Government of India, gave a plenary talk outlining the National Mission on Quantum Technologies and Applications (NMQTA), which was announced in the Budget, 2020. The NMQTA promises funding of 8000 Crore INR to forward the nation's massive push towards implementation of quantum technologies in India. The second half of the talk focussed on the role and needs of quantum science and technology in biology, ranging from photoreceptors that respond to single photons to the network of nerve cells in the brain. Major challenges in life sciences relate to accessing phenomena from the level of genes to an organism, and computational biology and neural sensing are among a few areas that will benefit from advances in quantum technology.

Session 2 – Chaired by Prof. Sai Vinjanampathy

Colloquium on Quantum Communication – In this colloquium, **Prof. Siddhartha Santra** (Physics, IIT Bombay), introduced quantum networks as schemes to distribute entanglement between separated quantum systems in order to perform certain quantum information processing tasks that are inaccessible using classical means. It looked at the potential of these networks, with some applications and at the state of the art, and also at problems in realising these networks. The colloquium concluded with an outlook highlighting the theoretical and experimental developments required in order to achieve global quantum networking.

Colloquium on Quantum Sensing – The next colloquium was presented by **Prof. Kasturi Saha** (Electrical Engineering, IIT Bombay), where she spoke about quantum sensors and its wider

applications. The talk introduced various aspects of quantum sensing ranging from atomic clocks and quantum radars to detection in Laser Interferometer Gravitational-Wave Observatory (LIGO project). The talk discussed sensors using elementary two-level quantum systems that behave as qubits to the more sophisticated colour defects in nitrogen-vacancy centres, which are used in magnetic field sensing up to pT level of sensitivity and also has biological applications. Other sensing devices such as quantum gravimeters and accelerometers being developed worldwide were also highlighted.

Panel Discussion – The panellists were Prof. Serge Haroche (**SH**), Prof. Arindam Ghosh (**AG**), Prof. R. Vijayaraghavan (**RV**), Mr. Abdul Kayum (**AK**) and Mr. Manoj Nambiar (**MN**). The discussion was moderated by Prof. Suddhasatta Mahapatra (**SM**) and Prof. Siddhartha Santra (**SS**), who tabled the questions for the panel to deliberate and respond. A summary of the discussion in the form of a Q&A is given below:

SM (to AG, RV and others): *Explain in brief what is the structure of the National Mission on Quantum Technologies and Applications (NMQTA) and who can participate?*

AG: For the second part, anyone in India can participate ranging from academia, institutes and government labs to industry at different levels. Provisions for international bodies to participate through collaborations, visitor programmes and other pathways are also available. The mission is global in terms of participation. The basic structure of NMQTA has four parts – quantum computing and simulations, communication, metrology and sensing and materials. Each of these have a specific mandate and set of deliverables, for example, in computing there is a mandate to create a specific number of qubits in a given platform or 500 km of ground/satellite based network in communication. Each part will be implemented through "hubs," which may consist of a few institutes, government bodies or industry partners. These hubs will be set up at different locations in India and proposals seeking funding will be submitted either as a consortium or an individual to these hubs.

SM (to RV): *How does the hub, spoke, and spike model work in NMQTA?*

RV: Hubs will be responsible for coordinating and executing the mission mandate and the deliverables. "Spoke" here refers to a consortium of institutes, industry partners working towards a common set of deliverables, whereas "spike" would refer to an individual lab working towards a smaller, specific part of the mandate. So, it is also a matter of scale in terms of what constitutes a spoke and a spike, and it is up to the hub to decide how it distributes these projects to ultimately achieve its overall mandate and deliverables.

SM (to SH): *Can you give us a historical perspective of how quantum physics worldwide stands to what is now the quantum technological ecosystem today?*

SH: The projects in India are similar to initiatives in France, other countries in Europe and also flagship projects under EU. But the idea is to support basic research along with applied technology.

There is a broad consensus in France and Europe that quantum science is still a field where a lot of basic research is necessary as a lot of questions in quantum computing remain unanswered. The French quantum initiative is more relaxed in terms of mandates, with more focus on research, and a strong sense of balance between basic and applied work. Fundamental aspects such as sensing, atomic clocks, gravimeters etc. that have application beyond quantum technology should be part of quantum initiatives, even though they are not as marketable as quantum computers. In France, there exists a dynamic start-up culture that is working on building quantum simulators and computers with a lot of private-sector and venture capital funding. There are niche areas that can be productive – peripheral technology, single photon sources, random number generators, as well as quantum software and algorithms, where India can play a leading role. However, the focus should be on fundamental science as several aspects of the field are still unclear, and the hope is to find new physics and new science, rather than focus too much on words such as quantum supremacy and quantum advantage.

SS (to AG, RV, and AK): *Can you clarify for the audience, what a National Mission is?*

AG: It is a mechanism to provide funding with the mission to achieve certain mandates or deliverables.

RV: The mandate is written down and specific but can also be perceived as a broad guideline. However, a National Mission has a well-defined goal in terms of what the Government is trying to achieve. It is not open to all research but only to those trying to achieve specific goals under the guidelines.

AK: A mission like NMQTA was designed by the academia and institutes with their own mandates and deliverables, which were approved by the Government. As such the Government has little say in the research, apart from administrative decisions.

SS (to all): *Is the mission philosophy motivated by science or technology?*

RV: As mentioned in the name, the mission is more technology oriented. From the Government perspective, a National Mission is different in scale and purpose from conventional research or science funding. But these missions do not have a single, narrow goal but rather a broader set of goals and deliverables. Each hub can also interpret and update these mandates with time.

SM (to MN): *At what point does industry (such as TCS) believe it is the right time to join the quantum ecosystem and what is the vision or business relevance in the immediate future?*

MN: TCS is involved in support, maintenance and design of large systems for enterprise customers worldwide. The business relevance arises from computationally intractable problems – such as decision-making problems, which are classically not solvable. Quantum computing is seen as the answer to solve such problems. In the near future, TCS as well as other companies are preparing to take the next steps and be "quantum ready." Even though only noisy quantum machines are available, we are hopeful that powerful machines will be available.

SS (to AK): *In terms of quantum communication, what is the Department of Telecommunication (DoT) approach to quantum security?*

AK: India is a net-consumer of technology and the goal for the present Government is for India to be a net-exporter of technology. DoT is closely coordinating with universities, institutes, and industry and also funding them to implement technologies in quantum communication, advance 5G, and 6G technologies. DoT has also set up inter-ministerial committees to study the national capabilities with regards to quantum attack on conventional communication and application of QKD. There is an urgent need for standardisation and certification of new quantum devices from startups, across different computing platforms. This is an agenda we have taken up and the DoT is committed to support development, certification and market-place access for all quantum technologies.

SS (to AK): *Are these DoT programmes independent of NMQTA?*

AK: Three different government bodies were initially in line to be funded through NMQTA – The Department of Science and Technology (DST), the Ministry of Electronics and Information Technology (MeitY) and DoT. However, MeitY and DoT are not associated with the Mission at this point. However, DoT will support the mandate of NMQTA in its own mission and objective and try to provide complementary resources.

SM (to MN): *In what ways will TCS interact with academia and what are its expectations?*

SS: TCS is not into building hardware, so it will surely look towards academia for support in this aspect. There are several ways to interact with TCS such as through its Research Scholar Programme or Co-innovation projects with academia and startups. TCS also hires faculty members as research advisors and offers research positions at different levels. TCS expects academia to provide knowledge it does not possess. For instance, how to work on the current noisy hardware and what kind of benefits are there.

SS (to AK): *Would DoT sensitise banks to adopt or benefit from QKD?*

AK: DoT is organising a quantum communication conclave on 27-28 March, 2023 to bring together people from different spheres, including developers, consumers and academia. We have invited banks, armed forces, and the telecom industry to come together to understand the field, and also for startups to showcase their products. All kinds of support in development, testing and market access is available.

SM (to all): *At this stage, what are the key messages to send to the government, policy makers, industry and colleagues?*

AG: Addressing my research colleagues – India needs to reject its old research culture and build the temperament and structure to take research from the lab to the market place in a collaborative, coherent manner. There should be a focus on bringing together people from different departments and disciplines, ranging from materials to computer science, to coherently work together to achieve specific research goals and deliverables.

SH: In France, CNRS brings people from different areas together with an overview of the research landscape and also promotes interdisciplinary research. A general advice to all governments, first, is to trust the scientists for the research, and second, to verify the work and evaluate the progress to plan for the future.

RV: A request to the Government would be to promote policy that makes science easier to do. With ample funding, the government should try to ease the process of acquiring equipment from India and abroad. Policies aimed at improving domestic production should not hurt basic research in science, especially in cases where such a production ecosystem does not exist.

Audience (to AG and RV): *Where are the benchmarks mentioned in NMQTA available?*

RV: The detailed project report should be available once NMQTA is formally launched.

Audience (to all): *Where does India stand on development of quantum material for computing architecture?*

AG: There are both direct and indirect quantum material development mandates related to NMQTA. For 2D materials, there are explicit goals for creating a million transistors on a single layer of graphene or related material. Also, more directly, development of topological materials to achieve fault tolerant computing platforms. Or simply finding Majorana modes. So, there is a mandate for search for new material for computing, as well as for modelling and discovery of novel materials.

Audience (to AK): *Is the Indian ecosystem developing any products that need standardisation or is it too early?*

AK: Any company that creates something will push for standardisation. If early standards are not adopted, then the value of intellectual property rights (IPR) will be diluted. There should be a push to obtain more IPRs in academia, and early standardisation will help benefit from these IPRs.

Audience (to MN): *What is the relation of international industry with respect to the Indian quantum ecosystem – do they perceive us as a market or collaborators?*

MN: TCS is the perfect example of how the international industry perceives India, where significant business is handled by TCS for its global enterprise customers. In quantum hardware, surely India is a market at this stage. However, for software and algorithms, India can be a net-producer and these developments are already taking place at different levels.

SS (to all panellists and the audience): *What would you do if you get 100 million logical qubits that are error corrected?*

Response: Find a drug for cancer, beat anybody in chess using a classical engine, solve physics problems, break passwords and codes and lead to what is called a "quantum catastrophe," we are between 'hype' and 'hope', and finally build a quantum version of chatGPT. The moderator highlighted a response from Maria Schuld at an IBM QML event – build a time machine to meet my grandmother and tell her that I built a quantum computer.

Poster Session – During the tea break, around 14 posters were presented by undergraduate, postgraduate and doctoral students, as well as postdoctoral fellows from various departments in IIT Bombay. A list of the poster presenters, with affiliation and title are given below:

- Seeding crystallization in time, **Parvinder Solanki** (PhD, Physics)
- Superconducting exchanging coupling mediated spin switching, **Sonam Bhakat** (PhD, Metallurgical Engineering and Materials Science)
- Entanglement Swapping of mixed states, **Md. Sohel Mondal** (PhD, Physics)
- Dynamic wide field-magnetometry using Nitrogen-vacancy-defects in diamond, **Shishir Dasika** (PhD, Electrical Engineering)
- Research at a Glance @ Pquest, **Aparajita Modak** (PhD, Electrical Engineering)
- Non-destructive rotational sensing using squeezed light interacting with atomic superfluid, **Rahul Gupta** (PhD, Physics)
- Development of a Compact Ansatz for Many Body Applications, **Dipanjali Halder** (PhD, Chemistry)
- Machine Learning embedded ansatz for Projective Quantum Eigensolver, **Sonaldeep Halder** (PhD, Chemistry)
- Josephson Junctions for cryogenic memory, **Pramod Kumar Sharma** (PhD, Metallurgical Engineering and Materials Science)
- Initialization of Spin-Orbit-Valley Coupled Qubits in Bilayer Graphene Double Quantum Dot, **Ankan Mukherjee** (BTech, Engineering Physics)
- $H_{5.9}Li_{0.1}Ru_2O_6$ (Ru^{3+} , $J_{eff} = 1/2$): A Kitaev Quantum Spin Liquid alternative to α - $RuCl_3$, **Sanjay Bachhar** (PhD, Physics)
- Quantum phase transitions in Higher Spin Heisenberg Model on Square Lattices, **Sankalp Kumar** (PhD, Physics)
- Superconducting exchange coupling mediated spin switching, **Biswajit Dutta** (PDF, Metallurgical Engineering and Materials Sciences)
- Dynamic-widefield-magnetometry using Nitrogen-vacancy-defects in Diamond, **Madhur Parashar** (PhD, Electrical Engineering)

Session 3 – Chaired by Prof. Sai Vinjanampathy

Introduction by the Director, IIT Bombay – **Prof. Subhasis Chaudhuri**, Director, IIT Bombay introduced Prof. Serge Haroche, the winner of the 2012 Nobel Prize in Physics, and invited him, on behalf of IIT Bombay, to deliver the distinguished institute lecture.

Distinguished Institute Lecture on Quantum Science with Rydberg Atoms – The distinguished lecture by **Prof. Serge Haroche** introduced the audience to the world of Rydberg atoms and its amazing role in studying quantum phenomena and developing quantum simulators. A series of atomic transitions in Hydrogen, known as the Rydberg transitions, were first identified by Johan Balmer and Johannes Rydberg in the late 19th century. A Rydberg atom is a highly excited atom that mimics these transitions and, in the process, obtains certain exaggerated

properties such as enormous sizes, very long lifetimes, high dipole strength among others. The lecture highlighted how these giant atoms can be prepared and manipulated by lasers with exquisite precision, and made to interact strongly with microwave photons, which can then be used to couple atoms with light. These atoms also interact with each other at distances which are very large at the atomic scale, with features that make them ideal tools to explore fundamental quantum phenomena, to build quantum gates and to realise quantum simulators of condensed matter systems.



DAY 2:

Session 1 – Chaired by Prof. Swaroop Ganguly

Talk on Post-Quantum and Quantum Cryptography: An overview – The first talk of the day was given by **Prof. Manoj Prabhakaran** (Computer Science and Engineering, IIT Bombay), who spoke about the implications of quantum communication and computation technologies on the theory and practice of cryptography. Firstly, algorithms in the quantum computation model, notably Shor's algorithm for integer factorization and its generalisations, can, in theory, break the most popular schemes in public-key cryptography. While these algorithms are currently not practical, due to the current limits of quantum computation hardware, and are far outperformed by algorithms implemented on classical hardware, future developments in quantum computing technology may make them practically relevant. This has created interest in so-called "post-quantum" cryptographic schemes, which appear to be immune to the potential speedups of quantum algorithms. Some of the candidates for post-quantum cryptography like lattice-based cryptography are of independent interest, and have received a lot of attention. On the other hand, at least one candidate that was considered promising for a long time recently turned out to be insecure even against classical adversaries. As such, it would be advisable to use post-quantum cryptography candidates in combination with currently common cryptographic schemes, rather than in lieu of them. The second part focuses on Quantum Cryptography, which relies on communication over quantum channels and minimises the reliance on computational hardness assumptions. Quantum Key Distribution (QKD) is the most



well-studied and commercially available application of Quantum Cryptography. However, QKD without relying on any computational hardness assumptions leads to very limited applicability for secure communication, due to the need for (short) pre-shared keys and extremely long keys to be derived using QKD. These limitations can be avoided by relying on computational hardness, though that restricts the scenarios where QKD is relevant. QKD is currently an experimental technology and comes with several caveats, compared to mainstream infrastructure for secure communication.

Talk on The Quantum Advantage in Decentralised Control – The next talk was by **Prof. Ankur Kulkarni** (Systems and Control Engineering, IIT Bombay), and focused on how behavioural or mixed strategies based on classical randomization does not improve the optimal cost of a team decision problem. However, by introducing a new class of entanglement-assisted stochastic strategies (static team decision problems that use entanglement to generate randomness), a numerical example of a decision problem with a cost strictly lower than the optimal cost achievable through classical strategies can be demonstrated. This exhibits the existence of a quantum advantage in decentralised control and introduces a novel decision and control paradigm with an enlarged space of physically-implementable control policies, and reveals a novel intuition to the powers and limitations of non-local quantum correlations.

Talk on Quantum Information Processing using Hybrid Quantum Systems – The following talk by **Prof. Himadri Shekhar Dhar** (Physics, IIT Bombay) provides a brief introduction to hybrid quantum systems and their synergistic advantage in implementing various quantum protocols ranging from quantum memories to transduction. In particular, hybrid quantum systems based on ensembles of spins, artificial qubits or atoms have been a very attractive prospective for quantum information processing. The speaker highlights a few specific problems related to the theoretical and computational study of such hybrid quantum systems designed using highly engineered spin ensembles such as atomic frequency combs or parametrically driven resonators. The theoretical results show how quantum states of light such as superposition of Fock states and macroscopic cat states are almost perfectly transferred to the spin ensemble and reemitted as photonic states with fidelity close to unity.

Colloquium on Quantum Materials – **Prof. Bhaskaran Muralidharan** (Electrical Engineering, IIT Bombay) presented a colloquium on one of the embedding pillars of quantum technologies – quantum materials and devices. Starting with a general overview, the talk focussed on technologically relevant and intensely pursued “topological” quantum matter and device applications. The colloquium first focused on what makes a “quantum material” – given that quantum theory is used in all materials! In doing so, it covered what can be explained via “low-level” quantum theory, in which macroscopic effects can be explained using classical theories. However, quantum materials require a deeper level quantum theory all the way up to the macroscale. After reinforcing these concepts, the talk covered the basics of how

“exemplary lane-discipline” of quantum channels is reinforced as a consequence of quantum topology – a higher level quantum theory is needed to explain these robust channels. Having covered these exciting aspects from a materials perspective, the talk focused on how to explore these functionalities and harness them as devices by introducing the tenets of “quantum transport” based device modelling platform. The focus of the last part is on how to harness such exotic and robust states in devices by covering some major research developments in IIT Bombay, primarily from a computational perspective.

Talk on Spintronics with Superconductors – In this talk, **Prof. Avradeep Pal** (Metallurgical Engineering and Materials Science, IIT Bombay) discusses how alternative, fast and energy efficient computing paradigms are being explored as CMOS miniaturisation approaches its limits. The talk focuses on one such paradigm of superconducting Rapid Single Flux Quantum (RFSQ) technology - which is predicted to be hugely energy efficient at the exascale level. It shows possible cryogenic devices that can be integrated as fast memory elements for RSFQ. In this context, recent progress at the Quantum Materials and Devices Lab. at IIT Bombay is discussed, particularly in Superconductor Ferromagnet multilayers and devices. The talk also showcases upcoming activities on development of various quantum sensors based on superconducting Nb based materials. These include devices such as NbN SIS junctions as THz detectors and NbTiN superconducting nanowire single-photon detectors.

Session 2 – Chaired by Prof. Siddhartha Santra

Talk on Quantum Biomimetic Electronic Nose and Electronic Tongue Sensor – The next talk by **Prof. Swaroop Ganguly** (Electrical Engineering, IIT Bombay), starts with a brief overview of quantum biology, introducing olfaction as a possible quantum biological system. This is followed by presentation of research in the group on the design of efficient quantum biomimetic (inelastic tunnelling based) electronic nose sensor devices; the realisation of an experimental measurement setup for inelastic tunnelling and its application as an electronic tongue sensor for heavy metal contaminants in water; and lastly, odour recognition and classification by physics-informed machine learning.

Talk on Achieving acceleration in Machine Learning through Quantum Computing – The talk by **Prof. Debanjan Bhowmik** (Electrical Engineering, IIT Bombay) was a review on the use of variational quantum algorithms for solving machine learning problems and combinatorial optimization problems, with an emphasis on the algorithms developed at IIT Bombay. Two specific algorithms developed for quantum machine learning were discussed. In the first algorithm, $SU(2)$ quantum operations were used to act as an activation function in a neural network. The results on Qiskit and commercial quantum hardware were discussed. In the second algorithm, quantum random access memory (RAM) and swap test circuits were used to process multiple training samples in a neural network, thereby obtaining an exponential time

complexity advantage. The talk also discussed the recent work in IIT Bombay related to the quantum approximate optimization algorithm (QAOA), with an emphasis on solving the NP-complete max-cut problem.

Plenary Talk on Testing Quantum Nature of Gravity – The plenary talk by **Prof. Sougato Bose** (University College London) highlighted an interesting example of how quantum technologies can inform fundamental physics. The talk considered a minimal model of “quantized” gravity where gravity acts as a quantum mechanical system that mediates interactions between two distant masses. He considered two falling quantum masses, one each in a mechanical analogue of a Mach-Zehnder interferometer. Since gravitational interactions are mediated by distance, there is the possibility of interference between the two paths describing the difference between the two possible separations between the distances, as displayed by the diagram below. The key point of the plenary talk was to consider the possibility of gravity as either being a classical medium or a quantum medium. If gravity is the former, it is only capable of mediating so-called stochastic local operations and classical communication (SLOCC) and cannot entangle the two quantum masses. On the other hand, if the medium that is gravity is quantum, such interactions can by the non-local nature of gravity entangle the two systems. Experimental implementations with levitating spheres were also discussed.

Vote of thanks – **Prof. Upendra Bhandarkar**, Associate Dean, Research & Development, IIT Bombay, thanked all the participants, conveners, organisers and student volunteers for their effort in successfully organising and managing the two-day event. The conveners thanked the institute dignitaries, senior officials and IRCC for their gracious support.



