

## Quantum frontiers and fundamentals, 2018\*

Ever since the advent of quantum mechanics during 1925–26, its fundamental conceptual issues continued to intrigue some of the best minds in physics like Einstein, Schrödinger, Louis de-Broglie, David Bohm and John Bell, giving rise to extensive searching debates. The celebrated Einstein–Podolsky–Rosen argument stimulated Schrödinger to bring out the importance of quantum entanglement as the ‘essential characteristic trait of quantum mechanics’. Subsequently, the seminal discovery of John Bell in 1964 of a theorem enabling empirical testing of the fundamental notions of locality and realism vis-à-vis quantum mechanical predictions paved the way for intimately linking the quantum foundational studies with actual experiments.

Then, from the 70s and 80s, this research area gradually started gaining momentum with experimental tests of Bell’s theorem, striking demonstrations of fundamental quantum phenomena like the Aharonov–Bohm effect, quantum Zeno effect followed by remarkable developments from the 1990s, stemming from spectacular progress in the relevant experimental technologies. This includes the coherent preparation and manipulation of quantum systems such as photons, electrons, neutrons, ions and molecules. These rapid strides have enabled comprehensive and deeper theoretical understanding as well as empirical probing of profound quantum features like quantum superposition, wave particle duality, nonlocality and contextuality, shedding light on a wide range of fundamental issues. Information theoretic facets of quantum entanglement have also been revealed ranging from dense coding, teleportation and entanglement swapping to quantum steering.

This, in turn, has given rise to a rich interplay between fundamental aspects of quantum mechanics and information theoretic studies, for instance, providing

insights into the nature of quantum correlations as resource for information theoretic tasks. Novel ideas of generalized quantum measurement, including that of weak measurement, have been developed with foundational implications and empirical ramifications. Probing fundamental quantum features for continuous variable systems and higher dimensional quantum systems are two other important areas of increasing current interest. In recent years considerable progress has been made in the area of testing fundamental aspects of quantum mechanics and the notion of macrorealism in the macroscopic domain. Finally, in the light of all these modern developments, revisiting the interpretational aspects of quantum mechanics for newer insights into foundational issues has gained renewed interest.

Against this backdrop, the conference titled ‘Quantum frontiers and fundamentals, 2018’ sought to bring together a wide section of researchers from India and different countries across the globe, both experimentalists and theorists, for critically deliberating upon the state of play and prospects in this research area.

While in India, research on foundational aspects of quantum mechanics was initiated from the late 70s and 80s, followed by studies on quantum information pursued from the late 90s, the efforts remained for long, limited to a few places involving a relatively small number of researchers. It is only in the last few years that the community of researchers in this field has started growing rapidly and at present centres of research are well spread across different parts of the country.

Though conferences in India on quantum foundations have been organized occasionally from early 90s, it is again only in recent years that there has been a significant surge in the number of such conferences, with the conferences focusing mainly on quantum foundational issues or on aspects of quantum information, with the central emphasis focused on theoretical studies.

In this context, QFF-2018 tried to be unique in its mandate, blending appropriately quantum fundamental aspects

with information-theoretic applications and providing equal emphasis to both theoretical research and experimental quantum technologies. Thus, speakers at QFF-2018 involved a healthy blending of experimentalists and theorists.

The conference started on the morning of the 30 April 2018 and was inaugurated by N. Mukunda. He recollected the history of this field in India and how emphasis and focus have changed with time to the present date.

The conference had around 100 registered participants, many of whom were students, post-doctoral fellows and young faculty. This exemplifies the high level of interest that this field now enjoys in our country. There were around 40 invited talks, 20 contributory talks and 31 posters presented at the conference.

Although a wide range of topics were covered, in this brief report only a flavour will be conveyed on types of topics and ideas that were deliberated upon.

Among the experimental studies reported, several technologies appeared in the discussions including photonic, NMR, opto-mechanical systems among others. Some of the topics covered include:

- Applications of single photon sources based on the process of spontaneous parametric down conversion (SPDC) were highlighted in terms of the following important applications – using a single photon interaction with a plasmonic beam splitter (metallic nanostructures on glass), and remote clock synchronization protocols using suitable entangled photon pairs.
- Using space-based quantum communication technologies, potential tests of fundamental aspects of quantum physics using Low Earth Orbit satellites were discussed and in this context, an overview was given on the status of the proposed Canadian mission.
- An appraisal of the prospects of a ‘quantum internet’ along with its technical, societal and economic implications was given.
- Loop-hole free tests of Bell’s inequality carried out at National Institute of Standards and Technology, Boulder,

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USA and the way such a test can be used to build a quantum random number generator was reported.

- Experiments were discussed illustrating the role of quantum optical systems in visualizing fundamental phenomena like experimentally simulating open time-like curves using polarization entangled photons.

- In the field of opto-mechanics, experiments were reported demonstrating a widely tunable, broadband motion amplifier based on graphene/silicon nitride systems.

- Experimental determination of the momentum transfer to the Bohmian trajectories in double-slit ‘which way’ measurements was reported thereby shedding new light on how ‘which way’ measurement affects interference fringes.

- Various applications of nuclear magnetic resonance (NMR) in implementing quantum information processing logic gates, search algorithms, quantum games and demonstrating fundamental quantum features were extensively reviewed.

A few interesting theoretical studies reported in the conference are mentioned below:

- Various aspects of quantum correlations, quantum nonlocality, quantum coherence and quantum contextuality.

- Critical aspects and significance of weak measurements.

- Modern developments related to uncertainty relations like measurement uncertainty relations, sum uncertainty relations and entropic uncertainty relations.

- Quantum phase space descriptions using continuous and discrete variables.

- Quantum limits on monitoring higher order quadratures of quantum fields.

- Aspects of quantum-classical boundary like quantum-classical correspondence for spin and test of macro-realism for nanoscale objects.

An important highlight of the conference was the Panel Discussion titled ‘Reflections on the Indian research sce-

nario: Quantum fundamentals and quantum information’ held on 2 May 2018 in the evening. Speakers comprised both senior and mid-career researchers who shared their views on the way Indian research activities in this area have been evolving as well as discussed their thoughts about future directions and about further fostering this research enterprise in India. While the overall view was very upbeat about the way the Indian research activities in this area have been growing, the key recommendations of the panel were as follows:

- (1) Forming a society for quantum information scientists in the country that will facilitate better exchange of ideas and collaboration.

- (2) Providing more thrust to experimental research in the area and enable fruitful collaborations between theorists and experimentalists.

- (3) Organizing more schools on specific topics in the field to increase awareness and knowledge in the student body and thus increase the pool of researchers in the area.

The Panel Discussion was particularly important at this stage in the context of some major national initiatives launched in India in this area. This was, for instance, exemplified by the fact that M. Shankaran, Deputy Director of ISRO Satellite Centre in Bengaluru, while attending the Panel Discussion, offered encouraging remarks about ISRO’s commitment towards getting intimately involved and providing substantial support for the relevant research programme in this area.

On behalf of the conference host institute, Raman Research Institute (RRI), a special talk was delivered by Urbasi Sinha that highlighted the different types of research which have been and are being undertaken in the broad area of quantum information science at RRI. This includes theoretical research as well as experimental work, especially at the dedicated Quantum Information and Computing (QuIC) lab. In this context, it is worth mentioning that ISRO has

recently initiated a mega project in collaboration with RRI for quantum experiments using satellite technology (QUEST). As the Principal Investigator of this project, Urbasi Sinha along with members of the Quantum Information and Computing lab at the RRI will be working on these experiments with ISRO support. One of the first experiments is expected to be a collaborative effort with the Quantum Photonics Lab at the Institute for Quantum Computing, University of Waterloo to aim for the establishment of a secure key between India and Canada.

Other than the rigorous and intense sessions with talks by invited and contributory participants as well as the poster session, the conference also provided plenty of opportunities for discussions among the participants not only during the meal times (all organized at the venue) but also during some social events organized including visits to the Raman museum at RRI as well as an excursion to the exotic Nandi Hills and its surrounding areas.

The conference ended on 4 May 2018. During the valedictory session, R. Rajaraman, member of the RRI Governing Council, appreciated the importance of the subject area and noted with satisfaction that RRI has been the host institute for such a conference. Usha Devi from Bangalore University briefly summarized the salient features of the conference. As with the inauguration, N. Mukunda also formally brought the conference to a close with the declaration that RRI will host the next QFF conference in 2020.

We look forward to making Quantum Frontiers and fundamentals a recurring conference series to serve as a platform which will bring in more technological elements for discussion in the coming years while retaining the unique flavour of merging ideas in quantum fundamentals with quantum frontiers, along with fostering the link between theoretical and experimental studies.

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