IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	Characterising and controlling complex quantum dynamics on quantum computers	
Project Number	**IMURA1027**	
Monash Main Supervisor (Name, Email Id, Phone)	Kavan Modi <kavan.modi@monash.edu>,	*Full name, Email*
Monash Co-supervisor(s) (Name, Email Id, Phone)		
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IITB Department:	Physics	

Research Clusters:

Research Themes:

Highlight which of the Academy's CLUSTERS this project will address? *(Please nominate JUST **one.** For more information, see www.iitbmonash.org)*		**Highlight which of the Academy's Theme(s) this project will address?** *(Feel free to nominate more than one. For more information, see www.iitbmonash.org)*	
1	*Material Science/Engineering (including Nano, Metallurgy)*	***1***	*Artificial Intelligence and Advanced Computational Modelling*
2	*Energy, Green Chem, Chemistry, Catalysis, Reaction Eng*	2	*Circular Economy*
3	*Math, CFD, Modelling, Manufacturing*	3	*Clean Energy*
4	*CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control*	4	*Health Sciences*
5	*Earth Sciences and Civil Engineering (Geo, Water, Climate)*	5	*Smart Materials*
6	*Bio, Stem Cells, Bio Chem, Pharma, Food*	6	*Sustainable Societies*
7	*Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng*	7	*Infrastructure*
8	*HSS, Design, Management*		

The research problem

Quantum computers are complex beasts.

A quantum computer is to be able to generate a complex quantum state to process information that a classical computer simply cannot. At the same time, quantum gates, the fundamental unit of quantum information processing, are defective in a (different) complex manner. The culmination of these two complexities lead to intractable problems, rendering the quantum computation to be not useful.

The Monash group has developed methods to describe and characterise the latter complexity. The IITB group possesses the knowledge of state-of-the-art quantum control methods. Combining these tools will allow us to generate quantum complexity in a desirable manner.

In order to combine these tools we will consider characterising and controlling driven quantum systems, and in particular Floquet Lindblad dynamics. The bulk of the work will be analytical, some numerics for building intuition, and finally, applying these ideas to real noisy quantum devices.

Along the way, we will use recently developed tools of quantum resource theories to quantify dynamical resources.

Project aims

We aim to find the border between complexity and simplicity. We will consider a simple Lindblad system and drive it. This will make the dynamics complex (chaotic), which we will characterise using methods of process tensor (Monash group), and control using the toolkit of quantum control (IITB group). In the final stage, we will quantify dynamical resources in such processes. These studies will lead to better quantum computers, as qubits naturally undergo Lindblad dynamics, and quantum gates drive them into complex states. Better characterisation and control is crucial for better quality quantum computers.

How skills/experience of the IITB and the Monash supervisor(s) support the proposed project

The PIs are long term collaborators and have co-authored several papers (see below) in the proposed field. KM is a world leader in non-Markovianity and open systems theory and SV has a long record of working in control theory and open systems theory. Both PIs have a long record of publications in quantum thermodynamics.

1 *Enhancing the charging power of quantum batteries*
F. Campaioli, F. Pollock, F. Binder, L. Céleri, J. Goold, S. Vinjanampathy, K. Modi
Physical Review Letters **118**, 150601 (2017) arXiv
Highlighted in *Nature Materials*, *Physics World*, *Physics*

2 *Correlations, operations and the second law of thermodynamics*
S. Vinjanampathy, K. Modi
International Journal of Quantum Information **14**, 1640033 (2016) arXiv

3 *Entropy bounds for quantum processes with initial correlations*
S. Vinjanampathy, K. Modi
Physical Review A **92**, 052310 (2015) arXiv

4 *Quantacell: Powerful charging of quantum batteries*
F. Binder, S. Vinjanampathy, K. Modi, J. Goold
New Journal of Physics **17**, 075015 (2015) arXiv
Highlighted in *Nature Materials*, *Physics World*, *Phys.org*, *Vice*, *ExtremeTech*

5 *Quantum thermodynamics of general quantum processes*
F. Binder, S. Vinjanampathy, K. Modi, J. Goold
Physical Review E **91**, 032119 (2015) arXiv

What is expected of the student when at IITB and when at Monash?

Highlight how the project will gain from the students stay at IITB and at Monash

At IITB, the student will benefit from the diverse group of SV who work on various aspects of open systems theory and control theory. During the initial three years at IITB, the student will be expected to learn basics of open system theory, basics of control theory and contribute towards various research projects in collaboration with KMs group.

Expected outcomes

Several manuscripts of high impact.

Three high-impact papers. New collaborations with industry. Tight bounds on controllable noise in quantum computers. Tight bounds on uncontrollable noise in quantum computers.

How will the project address the Goals of the above Themes?

Describe how the project will address the goals of one or more of the 6 Themes listed above.

Quantum computers are widely expected to be the new paradigm of computing. They will make a sizable impact on problems in the fields of logistics, fin-tech, drug and material discovery, new physics, etc. Yet, these devices cannot be built until we understand their emergent complexity due to noise. This project will lead the way in this front and is a natural fit for Advanced Computational Modelling. Additionally, there is room to integrate tools of Artificial Intelligence and Machine Learning as novel control modalities.

Potential RPCs from IITB and Monash

@ IITB : Himadri Shekhar Dhar, Siddhartha Santra
@ Monash Lincoln Turner

Capabilities and Degrees Required

List the ideal set of capabilities that a student should have for this project. Feel free to be as specific or as general as you like. These capabilities will be input into the online application form and students who opt for this project will be required to show that they can demonstrate these capabilities.

A robust background in the mathematics of quantum information theory
An working knowledge of quantum resource theories

Necessary Courses

PH 534 Quantum Information theory

Potential Collaborators

Please visit the IITB website www.iitb.ac.in OR Monash Website www.monash.edu to highlight some potential collaborators that would be best suited for the area of research you are intending to float.
Prof Daniel BurgarthMacquarie University (Sydney)
A/Prof Alexei GilchristMacquarie University (Sydney)
Dr Gerardo Paz SilvaGriffith University (Brisbane)
Dr Charles David HillUniversity Melbourne and IBM QHub (Melbourne)
Prof. T. S. Mahesh, IISER Pune.

Select up to **(4)** keywords from the Academy's approved keyword list **(available at http://www.iitbmonash.org/becoming-a-research-supervisor/)** relating to this project to make it easier for the students to apply.

non-Markovian noise, quantum control, quantum resource theory