**PROGRESS REPORT (APR. 2022 – MAR. 2023)** | **SAMPREET KALITA**

PMRF MAY 2020 LATERAL ENTRY (CYCLE 5) | 186121105, IIT GUWAHATI

# Theoretical Exploration of Quantum Technology with Cavity Optomechanical Systems

**RESEARCH TOPIC**

Cavity optomechanical systems[1] provide an ideal platform for the study of various dynamical phenomena and the effect of higher-order interactions and quantum noises in the microscopic as well as macroscopic domain. They also open exciting prospects in interdisciplinary research owing to their tunability and the ability to integrate them into hybrid quantum systems. My doctoral research focuses on the study of such systems, and the technological advancements they provide, through the analysis of quantum correlations like entanglement[2] and temporal relationships like synchronization[3]. My goal is to study such phenomena in scalable optomechanical and optoelectromechanical models for its applications in long-distance communication, on-chip architectures, and high-precision sensing, along with outlining communication schemes and contributing towards computational workflows.

## SUMMARY

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|---|---|---|---|
| Registered for Ph.D. | Jan. 1, 2019 | Coursework Grade | 9.23 |
| State-of-Art Seminar | Apr. 17, 2020 | Articles Published/Accepted | 7 |
| 1st Progress Seminar | Apr. 21, 2021 | Articles under Review/Preprints | 1 |
| 2nd Progress Seminar | Dec. 9, 2021 | Talks Delivered | 2 |
| 3rd Progress Seminar | Jun. 5, 2022 | Conferences & Schools Attended | 6 |
| 4th Progress Seminar | Dec. 15, 2022 | Hackathons & Workshops Completed | 3 |

## PREVIOUS WORKS

### Continuous Variable Quantum Entanglement in Optomechanical Systems: A Short Review

A. K. Sarma, S. Chakraborty and **S. Kalita** — Published on 6th January 2021
AVS Quantum Science **3**, 015901 (AIP) — 10.1116/5.0022349

### Switching of Quantum Synchronization in Coupled Optomechanical Oscillators

**S. Kalita** , S. Chakraborty and A. K. Sarma — Published on 2nd November 2021
Journal of Physics Communications **5**, 115006 (IOP) — 10.1088/2399-6528/ac3204

## PUBLISHED WORKS SINCE APRIL 2022

### Significant Optoelectrical Entanglement with Mechanical Squeezing in a Multi-modulated Optoelectromechanical System

**S. Kalita**, S. Shah and A. K. Sarma — Published on 3rd October 2022
Physical Review A **106**, 043501 (APS) — 10.1103/PhysRevA.106.043501

We studied the dynamical behaviour of the optoelectrical entanglement in an optoelectromechanical (OEM) system, where the optical and electrical modes were coupled via a common mechanical mode. The optical cavity was driven by a modulated laser beam and had a dissipative coupling with a mechanically compliant mirror. The mechanical mode was further coupled capacitively to a microwave LC circuit. We reported an enhancement in the optoelectrical entanglement and the squeezing of the mechanical position under the effect of various modulations in the laser drive, the voltage drive, and the mechanical spring constant. Notably, the maximum values of squeezing and entanglement oscillated alternately when both voltage and spring constant modulations were applied with the laser modulation (refer to Fig. 1).

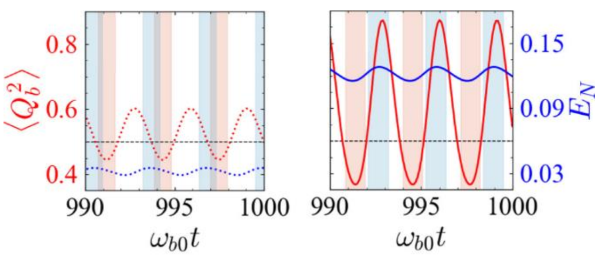


Fig. 1: Variance of mechanical position ($\langle Q_0^2 \rangle$, red lines) and optoelectrical entanglement ($E_N$, blue lines) in the presence of only laser modulation (left) and all three types of modulations (right). The dashed black lines represent the SQL for the variance and the shaded areas denote the regions of high squeezing and high entanglement. $\omega_{b0}$ is the base mechanical frequency.

Date: 25/04/2023

### Pump-probe Cavity Optomechanics with a Rotating Atomic Superfluid in a Ring

**S. Kalita**, P. Kumar, R. Kanamoto, M. Bhattacharya and A. K. Sarma
Physical Review A **107**, 013528 (APS)
Published on 26th January 2023
10.1103/PhysRevA.107.013525

We studied the coherent interference effects of an annularly trapped BEC inside a cavity using the formalism of cavity optomechanics[4]. Specifically, we examined the modification of the destructive interference between a strong pump field and a weak probe field by the atomic superfluid rotating under the influence of optical beams carrying orbital angular momentum (OAM). Under resonant conditions, we observed that double optomechanically induced transmission (OMIT) windows appear only in the presence of atomic superflow and the separation between the transmission dips provides an estimate of the magnitude of the quantized circulation (refer to Fig. 2). However, under non-resonant conditions, asymmetric Fano resonance profiles were observed. Moreover, we found that the dispersion profile of the probe beam is also modified by the atomic rotation, with a transition from slow to fast light.

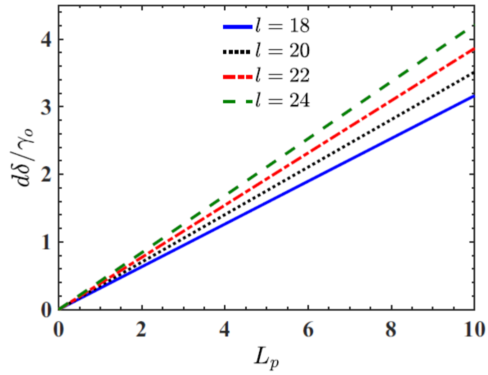


Fig. 2: Normalized separation between the observed transparency peaks ($d\delta$) as a function of the winding number of the BEC ($L_p$) for different values of the OAM number ($l$). Here, $\gamma$ is the cavity decay rate.

### Synchronization of a Superconducting Qubit to an Optical Field Mediated by a Mechanical Resonator

R. Nongthombam, **S. Kalita** and A. K. Sarma
Physical Review A **107**, 013528 (APS)
Published on 30th January 2023
10.1103/PhysRevA.107.013528

We studied the synchronization of a superconducting qubit to an external optical field in a hybrid system, with the microwave circuit coupled mechanically to a driven optomechanical cavity. For a single quantum trajectory run, we observed bistability of the qubit in the presence of laser drive. The rotation in one of the stable states was synced with an external optical drive (refer to Fig. 3). Our results indicated that the limit-cycle dynamics of the mechanical motion leads to the synchronization between the qubit's rotational state and the external laser drive.

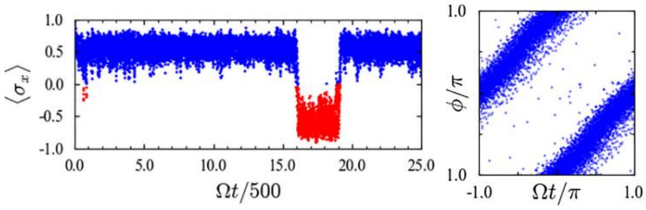


Fig. 3: *Left:* Bistability of the qubit along the polarization vector $\langle\sigma_x\rangle$. *Right:* Synchronization of the qubit polarization phase ($\phi = \tan^{-1}\{\langle\sigma_y\rangle/\langle\sigma_z\rangle\}$) with the phase of the external laser driving the cavity ($\Omega t$).

## ACCEPTED WORKS IN PRODUCTION

### The Quantum Optomechanics Toolbox

**S. Kalita** and A. K. Sarma
Proceedings of the 8th ICICT 2023, London, UK (Springer)
Accepted on 5th December 2022
Abstract

### Robust Mechanical Squeezing beyond 3 dB in a Quadratically-coupled Optomechanical System

P. Banerjee, **S. Kalita** and A. K. Sarma
Journal of Optical Society of America B (Optica)
Accepted on 11th April 2023
10.1364/JOSAB.483944

## REFERENCES

[1] M. Aspelmeyer, T. J. Kippenberg and F. Marquardt, *Cavity Optomechanics*, Rev. Mod. Phys. **86**, 1391 (2014)
[2] D. Vitali *et al*., *Optomechanical Entanglement between a Moveable Mirror and a Cavity Field*, Phys. Rev. Lett. **98**, 030405 (2007)
[3] A. Mari *et al*., *Measures of Quantum Synchronization in Continuous Variable Systems*, Phys. Rev. Lett. **111**, 103605 (2013)
[4] P. Kumar *et al*., *Cavity Optomechanical Sensing and Manipulation of an Atomic Persistent Current*, Phys. Rev. Lett. **127**, 113601 (2021)

Date: 25/04/2023