Second Nordic Workshop on Continuos-Variable Quantum Information

Chalmers, February 24-45 lunch to lunch.

Important information: on February 24th we meet at the entrance of MC2 (Kemivägen 9) at 11:45 to go together to the lunch restaurant Wijkanders (Vera Sandbergs allé 5B). We provide lunch coupons so please be on time to grab yours!

Dinner takes place at Wijkanders.

Talks and poster session are in room Luftbryggan, Kemivägen 9, stair A, 8th floor.

	24 February		
13:00-13:30	Axel Eriksson/ Lukas Splitthoff	Overview of Chalmers CV experimental team	Chalmers
13:30-14:00	Nils Nerpin	Optimization of SNAIL	Chalmers
14:00-14:30	Rui Wang	Quantifying non-Gaussianity with the SNAP-rank	Chalmers
14:30-15:00	Break		
15:00-15:30	Fabio Lingua/ Juan Carlos Rivera	CV Cluster States in Microwave Frequency Comb	KTH
15:30-16:00	Sreenath K. Manikandan	Detecting Acoherence in Radiation Fields	Nordita/ WINQ
16:00-16:30	Sofia Qvarfort	TBC	WINQ
16:30-17:00	Lab tour		

17:00-18:30	Break + Poster session		
18:30	Dinner		
	25 February		
09:00-09:30	Kirill Petrovnin	Microwave sensing at parametric criticality	Aalto University
09:30-10:00	Mukhanova Ekaterina	Homodyne detection of microwaves using traveling wave Josephson parametric amplifiers	Aalto University
10:00-10:30	Ilari Lilja	Entanglement under multiple parametric excitations in quantum circuits	Aalto University
10:30-11:00	Break		
11:00-11:30	Cameron Calcluth	Classical simulation of circuits with realistic Gottesman-Kitaev-Preskill states	Chalmers
11:30-12:00	Maryam Khanahmadi	Engineered Environment-Assisted Generation of Quantum Bosonic State Wavepackets	Chalmers
12:00-13:00	Lunch		

Abstracts (alphabetical order):

Cameron Calcluth: Classical simulation of circuits with realistic Gottesman-Kitaev-Preskill states
Classically simulating circuits with bosonic codes is a challenging task due to the prohibitive cost of simulating quantum systems with many, possibly infinite, energy levels. We propose an algorithm to simulate circuits with encoded Gottesman-Kitaev-Preskill states, specifically for odd-dimensional encoded qudits. Our approach is tailored to be especially effective in the most challenging but practically relevant regime, where the codeword states exhibit high (but finite) squeezing. The runtime of the algorithm scales inversely with the degree of squeezing, enabling fast simulation of certain large-scale circuits with a high degree of squeezing.

Mukhanova Ekaterina: Homodyne detection of microwaves using traveling wave Josephson parametric amplifiers
Homodyne detection has played an important role in quantum optics metrology since the early 1980'ies. It has been useful, in particular, for detecting non-classical states, which is essential for studies of Continuous Variable (CV) quantum information. We have constructed a 5-6 GHz microwave system that mimics a

typical homodyne detector [1]. Our system contains a 180-degree hybrid, two independent amplified signal channels with TWJPA amplifiers, and a GHz multichannel lock-in amplifier for phase-sensitive detection. This technique is based on the principle that only the correlated signal is amplified while uncorrelated noise introduced by two separate amplification stages is effectively suppressed. We will describe the operation principle, and characteristics of the correlation setup, and discuss the first results obtained on a Josephson parametric amplifier as a source. This work has benefited from the joint project “Gaussian and non-Gaussian cluster states for quantum computation and quantum sensing” funded by WACQT and InstituteQ.

Maryam Khanahmadi: Engineered Environment-Assisted Generation of Quantum Bosonic State Wavepackets

This work presents a hardware-efficient approach for generating propagating non-Gaussian bosonic states on superconducting circuit platforms. This method enables secure quantum communication between distant quantum memories by deterministically preparing microwave-traveling wave packets. Rather than producing the non-Gaussian states in a cavity mode by a high-order nonlinear Hamiltonian and subsequently releasing it to a waveguide, we propose and analyze a scheme that applies simultaneously a coherent excitation and a combination of linear and nonlinear losses to form and emit Schr\"odinger cat states directly into output pulses. By leveraging the effective anti-Hermitian Hamiltonian induced by losses, which achieves high-order nonlinearities more easily than its Hermitian counterpart, the technique enables efficient and deterministic creation of complex propagating quantum states, including two- and four-component cat states, grid states, and pair cat states.

Ilari Lilja: Entanglement under multiple parametric excitations in quantum circuits

Continuous variable non-classical states provide an essential resource in continuous variable quantum information protocols. For example, they can be found in the formation of Gaussian cluster states in frequency space with the concurrent application of multiple parametric excitations. However, we recently observed that the pairwise entanglement between coupled modes decreases with each subsequent inclusion of an additional parametric excitation, which significantly limits the usefulness of the formed state. To model this behavior, we employ methods based on general-dyne monitoring of the covariance matrix in our parametrically driven system [1]. Graph theory calculus is utilized to infer the full set of coupled modes, defining the structure of the Hamiltonian matrix which together with drift and diffusion matrices can be employed to construct the steady state solution. Logarithmic negativity between two primary modes is tracked as the characteristic of merit. Experimental results are compared to the model and are found to be in good agreement with the theory.

[1] A. Serafini, Quantum Continuous Variables: A Primer of Theoretical Methods (CRC Press, Boca Raton, 2017)

Fabio Lingua: CV Cluster States in Microwave Frequency Comb

We describe an experiment demonstrating the generation of three independent square-ladder continuous-variable cluster states with up to 94 qumodes of a microwave frequency comb. This entanglement structure at a large scale is realized by injecting vacuum fluctuations into a Josephson Parametric Amplifier pumped by three coherent signals around twice its resonance frequency, each having a particular well-defined phase relation. We reach up to 1.4 dB of squeezing of the nullifier which verifies the cluster state on the square ladder graph. Our results are consistent with a more familiar measure of two-mode squeezing, where we find up to 5.42 dB for one pump, and up to 1 dB for three pumps.

Nils Nerpin: Optimal Control of a SNAIL-resonator
In this talk I will discuss the controls and effective modeling of a resonator terminated by a Superconducting Nonlinear Asymmetric Inductive eLement (SNAIL). By piercing the SNAIL with a magnetic flux, one can achieve universal control while heavily suppressing static Kerr effects of the fundamental mode of the resonator. This universal control is achieved by resonant driving, which leads us to an effective Hamiltonian of the system. A set of resonant pulses can then be engineered to achieve some non-Gaussian target state, such as cubic phase states or cat states, by means of optimal control using the effective Hamiltonian. Finally, the promises and challenges of extending this approach to a resonator terminated by an Asymmetrically Threaded Superconducting quantum interference device (ATS) are discussed.

Kirill Petrovnin: Microwave sensing at parametric criticality
We study a Josephson parametric system at parametric criticality. Our theoretical and experimental results show that the system is highly sensitive to external excitations near transition border. These results pave the way for applications in single-photon detection and integration into complex quantum systems, including those involving superconducting and spin qubits. Furthermore, the dynamics of parametrically driven dissipative Kerr systems hold fundamental importance, offering a unifying framework for various quantum and condensed matter models.

Lukas Splitthoff: Towards demonstrating verified quantum speedup in a bosonic superconducting processor
We present our progress in developing a superconducting platform for bosonic quantum computing, with a focus on demonstrating verifiable quantum speedup through boson sampling. Achieving this ambitious goal relies on three key building blocks: the deterministic preparation of nonclassical states in high-dimensional bosonic modes, the realization of high-fidelity beam-splitting interactions with all-to-all connectivity, and the implementation of efficient homodyne/heterodyne detection and photon-counting measurements. In this talk, we will discuss our group-wide effort to develop and integrate these critical components into a unified platform. Specifically, we will highlight experimental advancements, including fast state preparation enabled by combined charge and flux drives of nonlinear cavities, as well as a novel protocol for homodyne and heterodyne detection on stationary bosonic modes, facilitated by an ancillary qubit. Finally, we will outline our strategy for quantum verification and the path toward achieving verified quantum speedup. This work represents a significant step forward in the quest to harness quantum advantages in a scalable and verifiable manner.

Rui Wang: Quantifying non-Gaussianity with the SNAP-rank
Quantum resource theories provide a powerful framework for characterizing and quantifying resources crucial to quantum information tasks. In this work, we introduce a resource measure for non-Gaussianity, a necessary element for achieving universal continuous-variable quantum computation (CVQC). In contrast to previous measures, such as the stellar rank which corresponds to the number of photon additions, our approach directly connects the resourcefulness of a state to the experimental procedure required for its generation in a circuit quantum electrodynamics architecture. Specifically, we focus on the selective number-dependent arbitrary phase (SNAP) gate, a non-linear operation forming a universal gate set for CVQC with the displacement gate. We define the SNAP-rank as the minimum number of SNAP gates needed to prepare a given non-Gaussian state from a Gaussian reference state and prove that it provides a measure of non-Gaussianity. We use this framework to characterize states that can be prepared with few SNAP gates and Gaussian operations, and we compare the fidelity profiles for families of non-Gaussian states as a function of SNAP-rank and stellar rank. We show that using a few SNAP gates with Gaussian operations yields generated states with higher fidelity to target non-Gaussian states as compared to those produced by photon additions as quantified by the stellar rank.