

Quantum technology seminar
20/3 2024
Joakim Bergli

Topics of interest (partial)

- Decoherence
- Error correcting codes
- Dynamics of open quantum systems (synchronization)
- Topological materials
- Information and entropy
- Quantum optics
- Quantum sensors/measurements
- Foundational problems in quantum mechanics

Projects/collaborations

- Mathematics for quantum computation and many-body theory (QOMBINE).

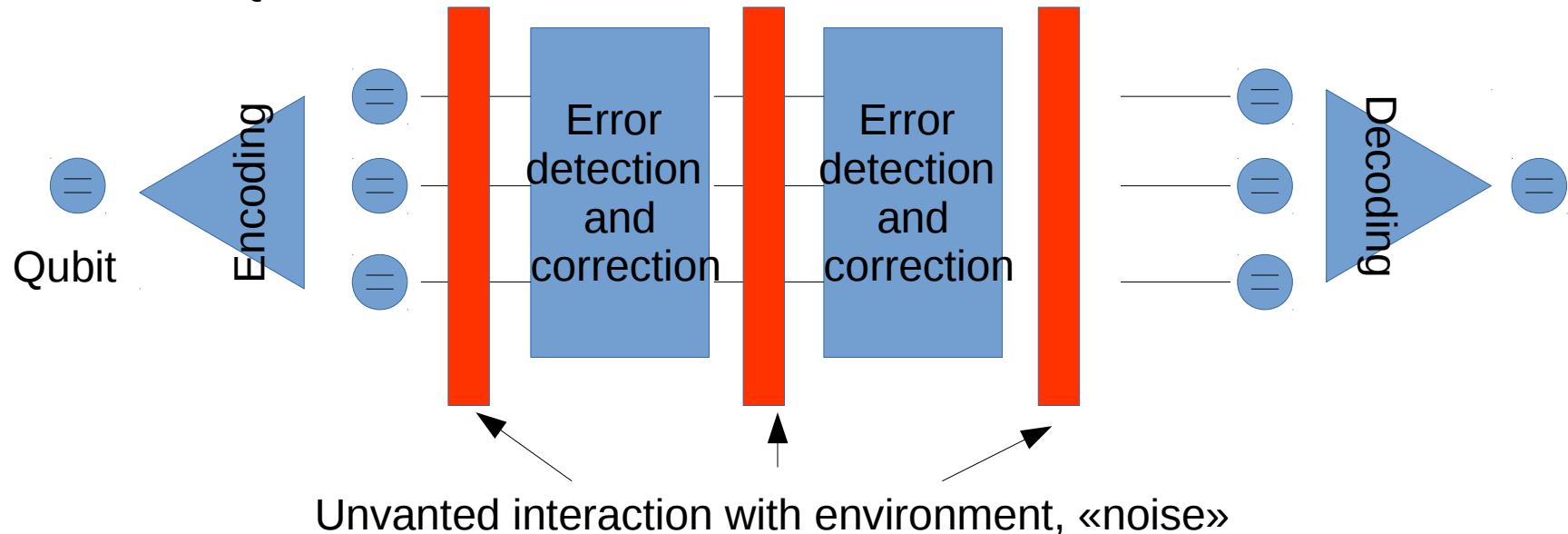
UiO Mathematics + Physics + Chemistry.

1 PhD student i physics

- Quantum Technology Education Consortium between Norway, South America and Cuba (QTECNOS).
- Gemini centre on quantum computing.
SINTEF + UiO + NTNU
- NSM. 1 PhD student.

Quantum error correction (bosonic codes)

«Classical» Quantum error correction

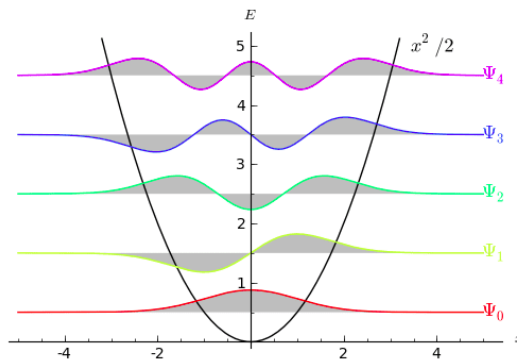
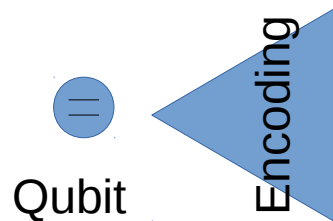


The information is protected from decoherence by the environment by duplication – More qubits are needed and the repeated information can be used to correct errors.

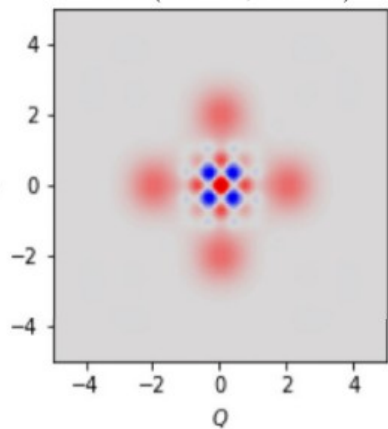
In different language: Information is encoded in a subspace of a larger Hilbert space.

Bosonic codes

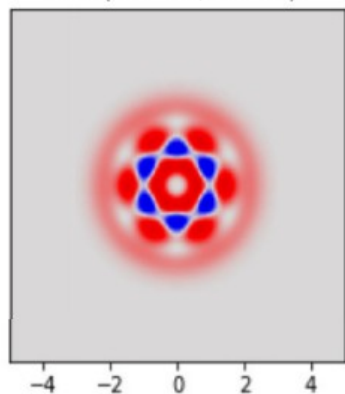
Instead of encoding one qubit in n qubits we use a harmonic oscillator (infinite dimensional Hilbert space)



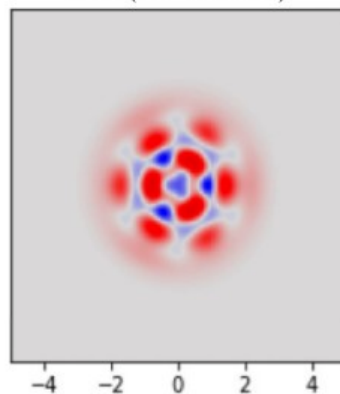
$\text{cat}(\alpha = 2, S = 1)$



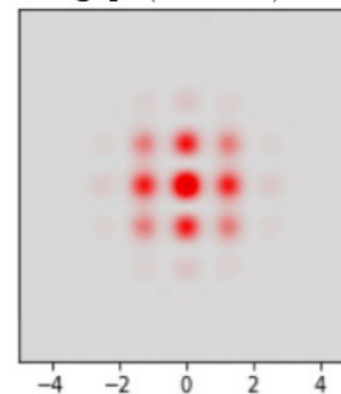
$\text{bin}(N = 1, S = 2)$



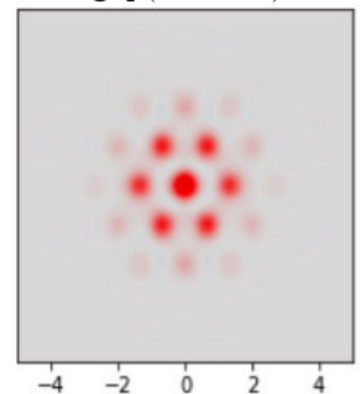
$\text{num}(\bar{n} = 2.696)$



$\text{gkps}(\Delta = 0.5)$



$\text{gkp}(\Delta = 0.5)$



Real-time quantum error correction beyond break-even

Nature | Vol 616 | 6 April 2023

<https://doi.org/10.1038/s41586-023-05782-6>

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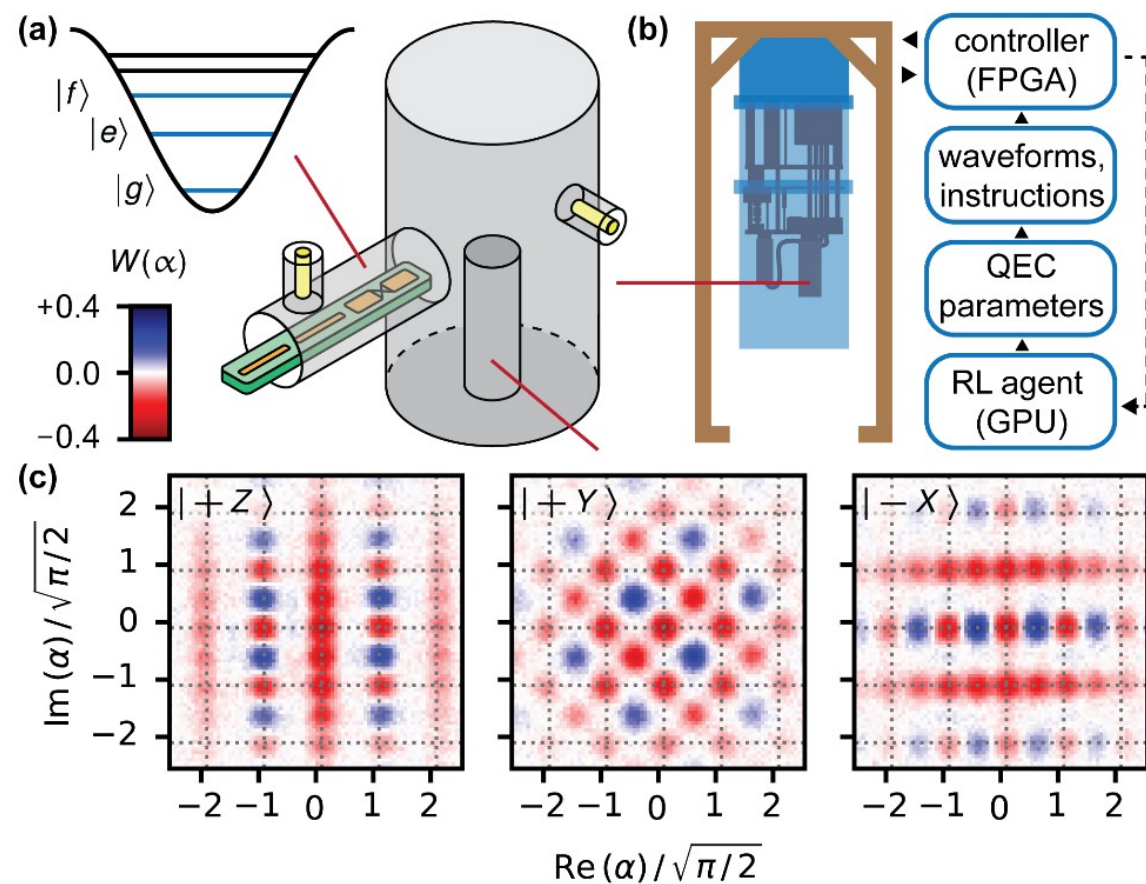
Accepted: 2 February 2023

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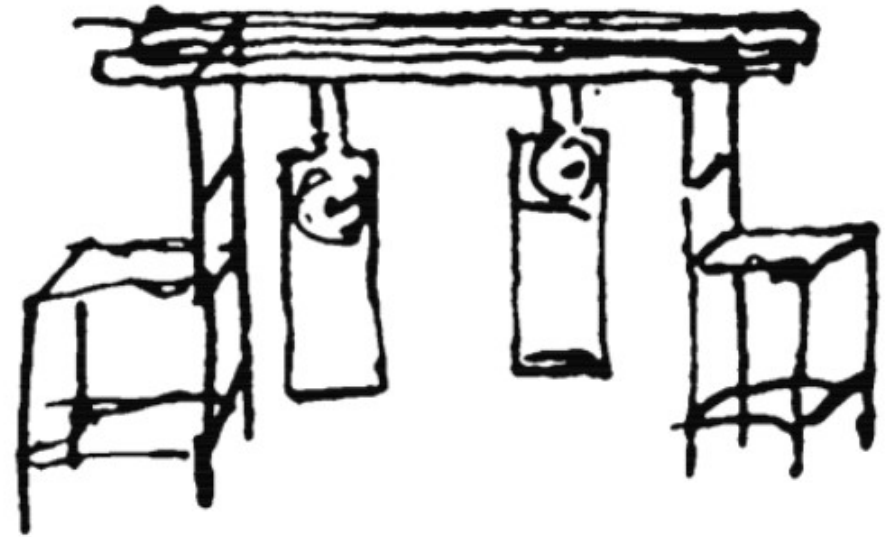
 Check for updates

V. V. Sivak^{1,2,3,6}✉, A. Eickbusch^{1,2,3}, B. Royer^{1,2,3,4,5}, S. Singh^{1,2,3}, I. Tsioutsios^{1,2,3}, S. Ganjam^{1,2,3}, A. Miano^{1,2,3}, B. L. Brock^{1,2,3}, A. Z. Ding^{1,2,3}, L. Frunzio^{1,2,3}, S. M. Girvin^{1,2,3}, R. J. Schoelkopf^{1,2,3} & M. H. Devoret^{1,2,3}✉

The ambition of harnessing the quantum for computation is at odds with the fundamental phenomenon of decoherence. The purpose of quantum error correction

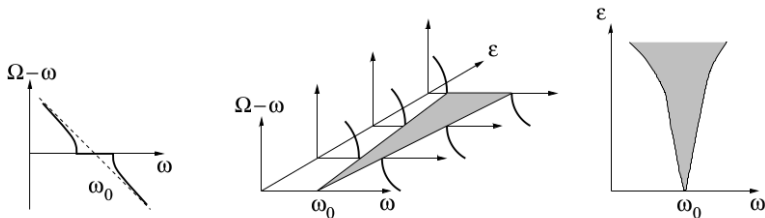


Synchronization (quantum trajectories)



Christiaan Huygens (1665): Two pendulum clocks on the same support will synchronize their pendulums, even if their frequencies are slightly different in isolation.

Signatures of synchronization



The parameters determining synchronization

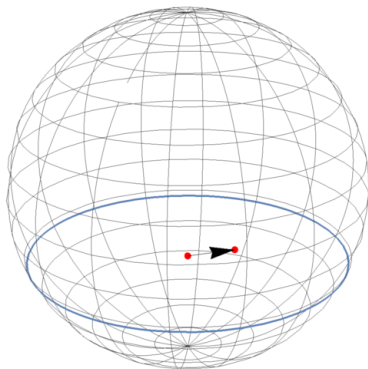
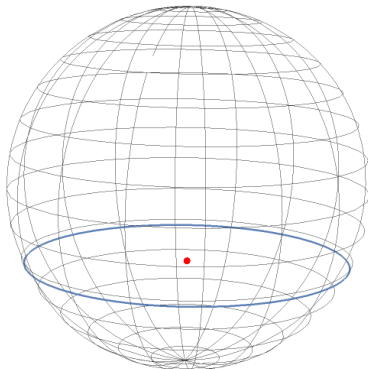
- ▶ Natural frequency of the oscillator, ω_0 .
- ▶ Frequency of the external force, ω .
- ▶ Frequency of the oscillator in response to the force, Ω .
- ▶ Strength of the external force, ϵ .

Stationary state solution

$$H = \frac{\hbar}{2}\omega_0\sigma_z + \hbar\frac{\epsilon}{4}(\cos\omega t\sigma_x - \sin\omega t\sigma_y)$$

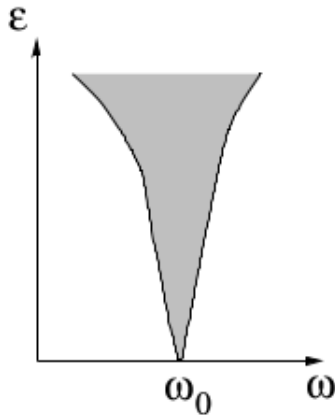
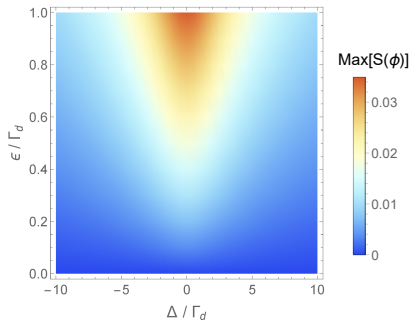
The Bloch vector is shifted from the axis.
Without signal ($\epsilon = 0$)

With signal ($\epsilon > 0$)



Detecting synchronization

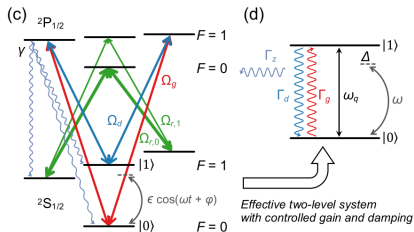
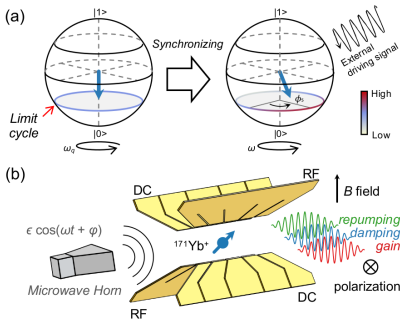
$$\frac{1}{8} \sqrt{m_x^2 + m_y^2}$$



The boundary of the synchronization region is not sharp like in the classical case.

Experiment

Quantum synchronization of a single trapped-ion qubit, Liyun Zhang et al., Phys. Rev. Research 5, 033209 (2023).



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