Small Quantum: Prof. George Vahala – quantum algorithms

DEVELOP QUBIT LATTICE ALGORITHMS (QLA) for NONLINEAR PHYSICS

- given the PDE of interest [e.g., Nonlinear Schrodinger Eq., Quantum Turbulence in BECs, Maxwell Eqs. , …]
- Determine the interconnect between qubits **Q**(x,t) ⟷ physics (e.g., wave function ψ or **E**-field ..)
  so the evolution equation for the qubits : $\frac{\partial \boldsymbol{Q}}{\partial t} = H\,\boldsymbol{Q}$ is unitary [nontrivial step : Dyson Map…]
- Devise an interleaved sequence of unitary collision-streaming operators that recover the evolution equation perturbatively.

e.g., 1D Maxwell . 8 qubits/lattice site. n(x) – refractive index

Qubits ⟷ ***E, B***

$$\mathbf{F}^{\pm} = n(x)\mathbf{E} \pm i\frac{\mathbf{B}}{\sqrt{\mu_0}}.$$

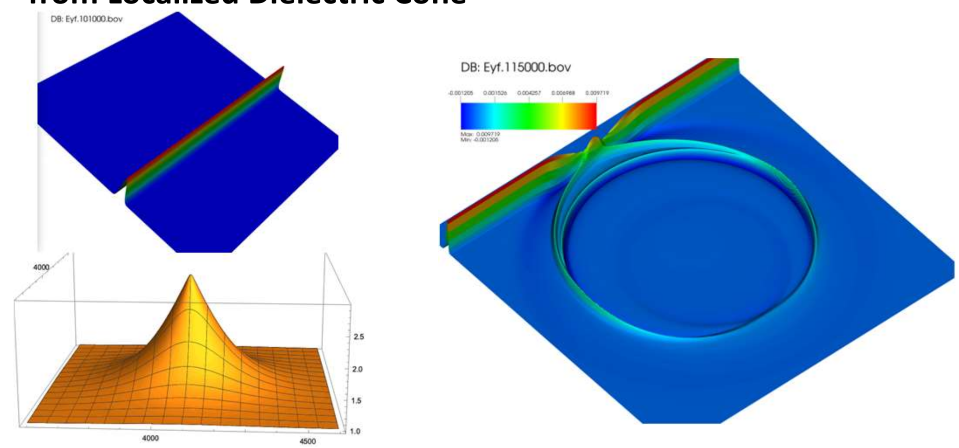
$$(q_0, q_1, \dots q_7) = \begin{pmatrix} -F_x^{\pm} \pm iF_y^{\pm} \\ F_z^{\pm} \\ F_z^{\pm} \\ F_x^{\pm} \pm iF_y^{\pm} \end{pmatrix},$$

Qubit equations

$$\frac{\partial}{\partial t}\begin{pmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{pmatrix} = -\frac{1}{n(x)}\frac{\partial}{\partial x}\begin{pmatrix} q_2 \\ q_3 \\ q_0 \\ q_1 \end{pmatrix} - \frac{n'(x)}{2n^2(x)}\begin{pmatrix} q_1 + q_6 \\ q_0 - q_7 \\ q_3 - q_4 \\ q_2 + q_5 \end{pmatrix}$$

$$\frac{\partial}{\partial t}\begin{pmatrix} q_4 \\ q_5 \\ q_6 \\ q_7 \end{pmatrix} = -\frac{1}{n(x)}\frac{\partial}{\partial x}\begin{pmatrix} q_6 \\ q_7 \\ q_4 \\ q_5 \end{pmatrix} - \frac{n'(x)}{2n^2(x)}\begin{pmatrix} q_5 + q_2 \\ q_4 - q_3 \\ q_7 - q_0 \\ q_6 + q_1 \end{pmatrix}$$

2D Electromagnetic Scattering of 1D Plane Pulse from Localized Dielectric Cone



Small Quantum: Prof. Enrico Rossi – Quantum Materials

Quantum computing -> Anyons/Majoranas

To build a quantum computer we need Fault Tolerant qubits

We need error correction

1 logical qubit ->
1000 or more physical qubits

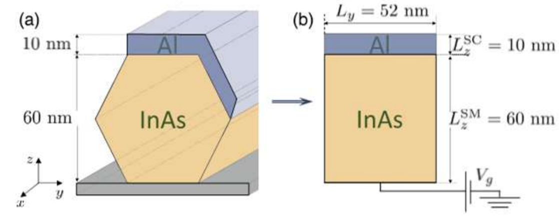
Error correction codes: **Surface codes**

Kitaev realized that when using surface codes the state of a bit is really encoded in a topological state of the array of physical qubits

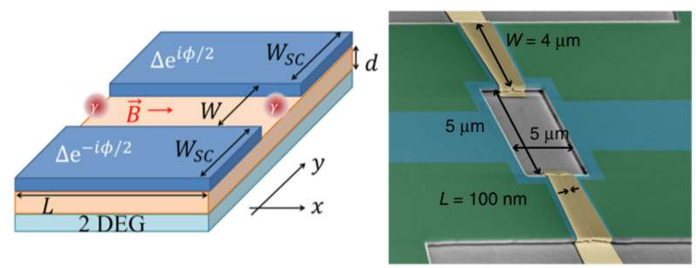
Why not to use systems that are intrinsically topological?

Topological superconductors: they have ground-state non-abelian anyons.
No excited states are used to encode information -> No decoherence

Majorana nanowires



Topological Josephson junctions

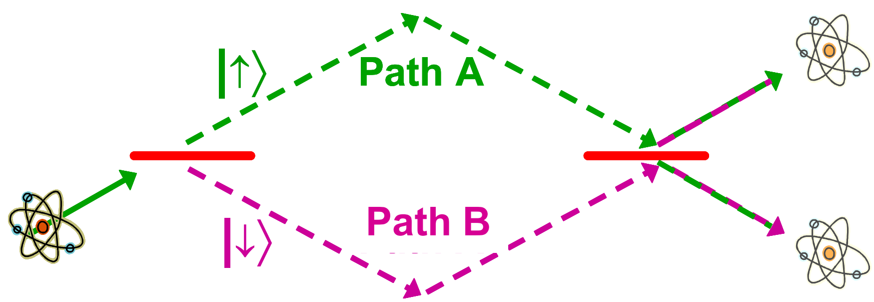


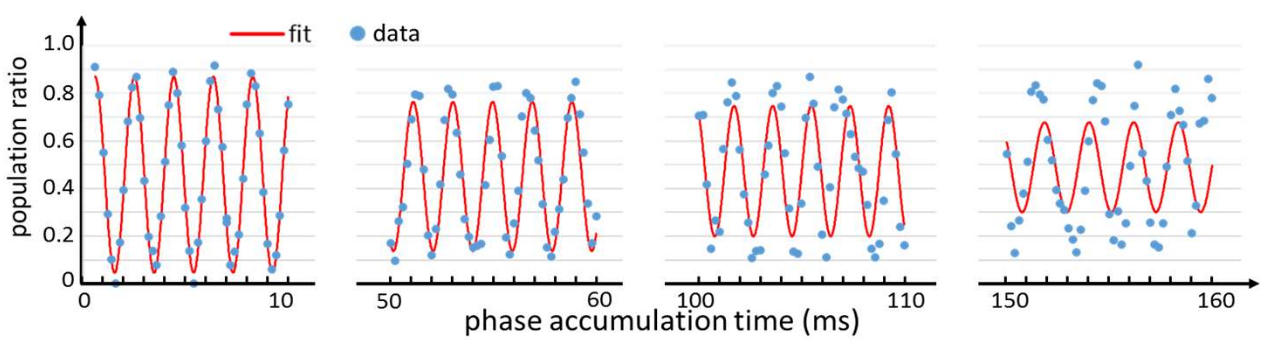
Small Quantum: Prof. Seth Aubin – Cold quantum atoms in quantum wells

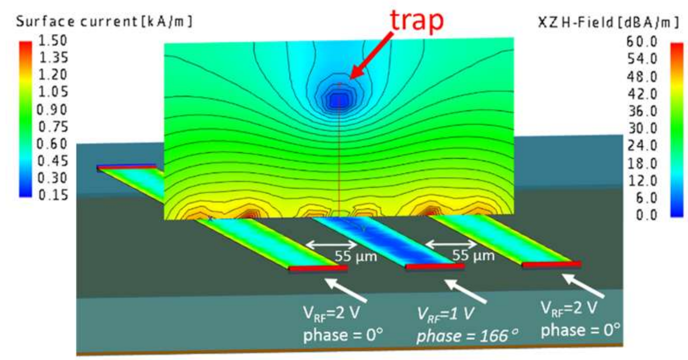
Spin-dependent interferometer.

→ An ***"atomic clock"*** with spatially separated clock states.

→ Designed to work with ultracold thermal atoms, quantum gases.

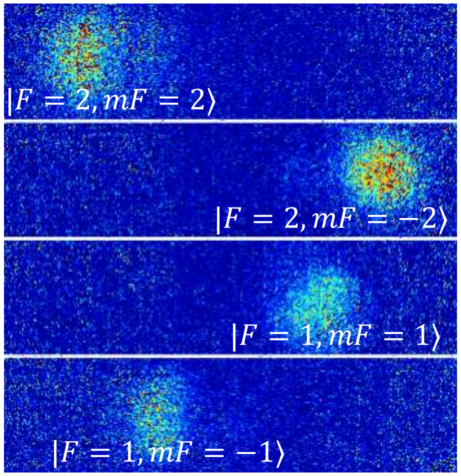




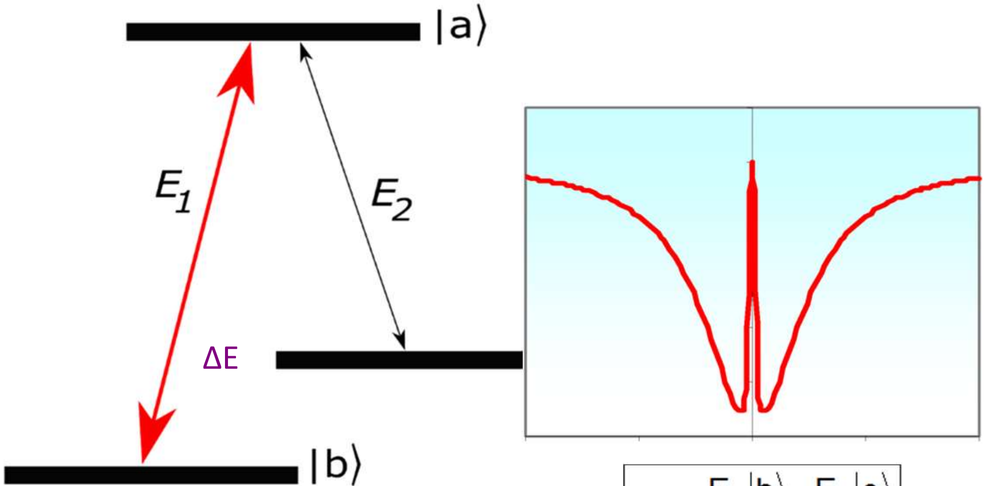


[FEKO EM simulations at 6.8 GHz]

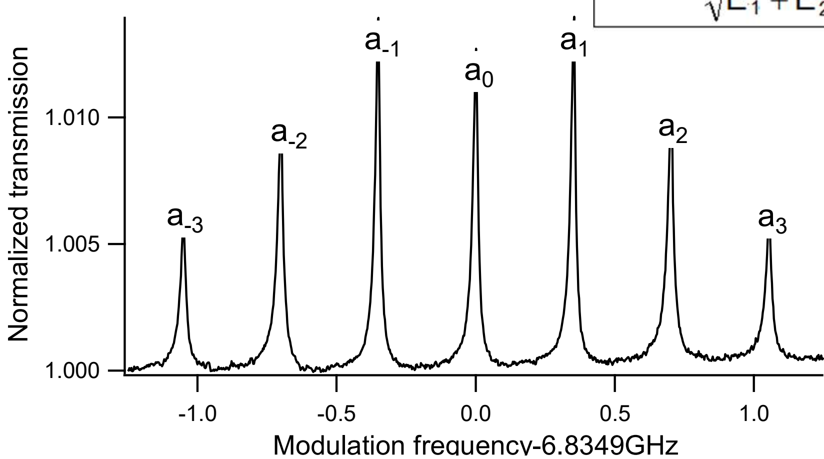
RF chip trap (spin-dependent)

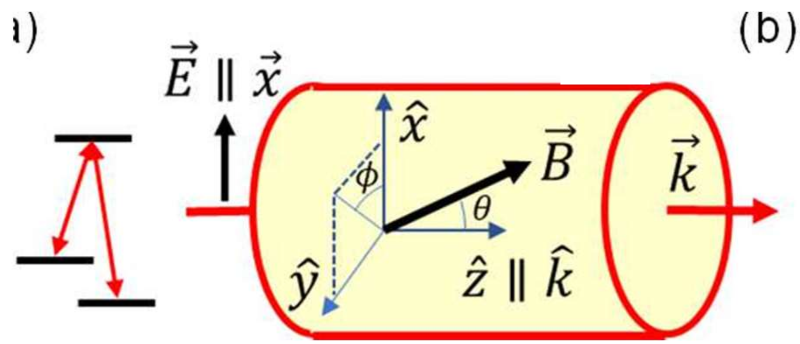


Small Quantum: Profs. Eugeniy Mikhailov and Irina Novikova – Hot quantum atoms and quantum light



$$|D\rangle = \frac{E_1|b\rangle - E_2|c\rangle}{\sqrt{E_1^2 + E_2^2}}$$

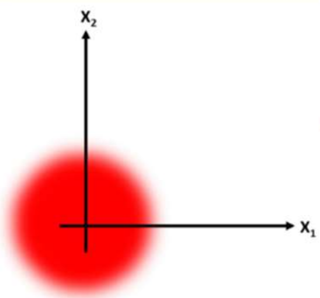




Compact clock: stability 10^{-12}
Magnetometer: sensitivity 10pT and potentially 100fT in small volume

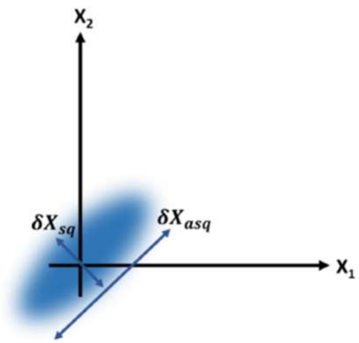
Small Quantum: Prof. Eugeniy Mikhailov and Irina Novikova – Hot quantum atoms and quantum lignt

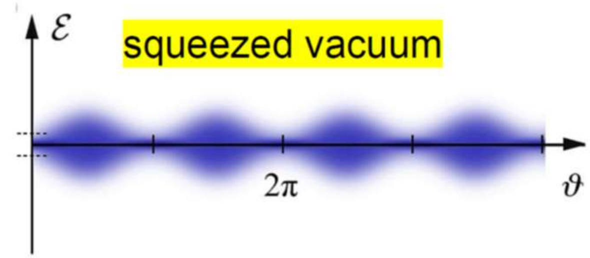
Coherent vacuum



Quadrature squeezing

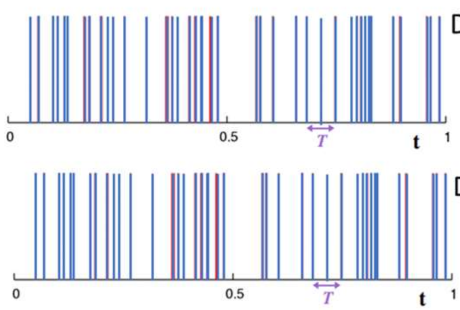
$$\hat{S}|\alpha\rangle = e^{\xi(\hat{a}\hat{a}-\hat{a}^\dagger\hat{a}^\dagger)}|\alpha\rangle$$

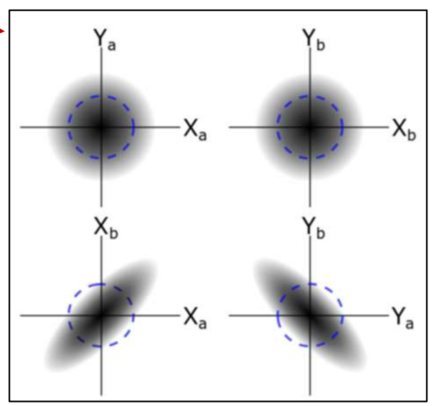




Two-mode squeezing

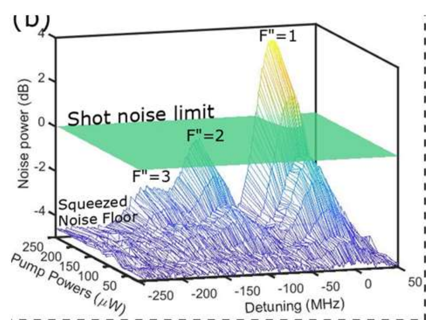
$$\hat{S} = e^{\xi(\hat{b}^\dagger\hat{a}^\dagger - \hat{a}\hat{b})}$$



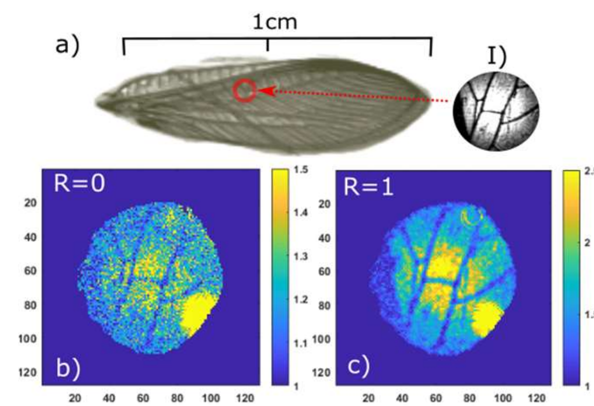


Applications

Quantum-enhanced measurements



Quantum-noise imaging



Quantum-Nuclear collaboration: Quantum Electron Tracker
Mikhailov, Novikova, Aubin, Averett

A table-top prototype detector of charged particles using atomic optical properties