Detecting fundamental Physics using Quantum probes

"Gravity sensing using Stark localization "

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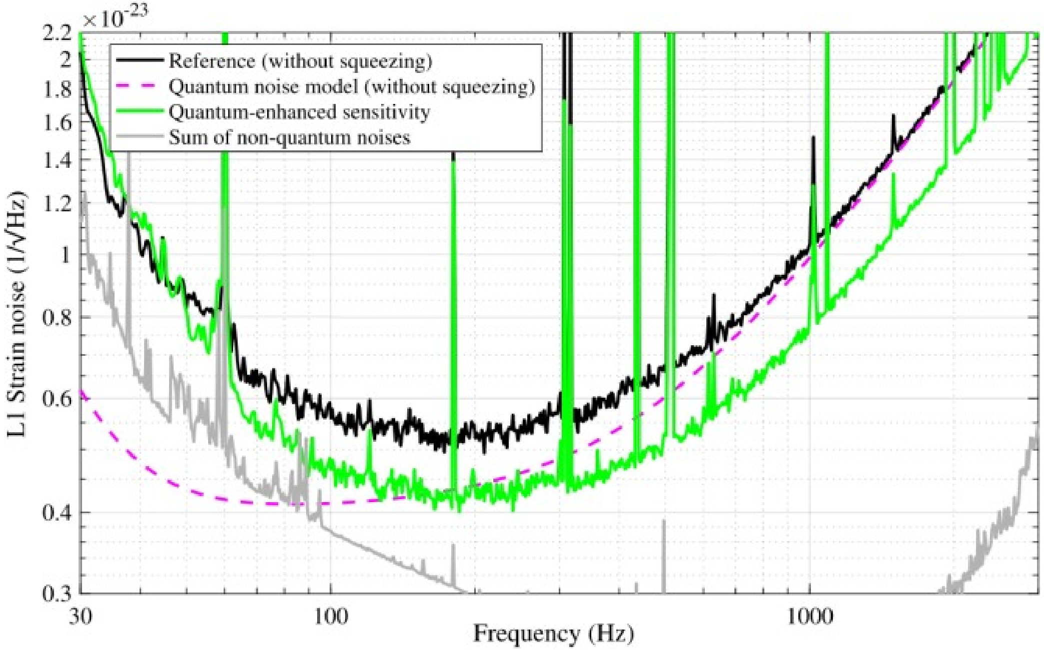
OUTLINE

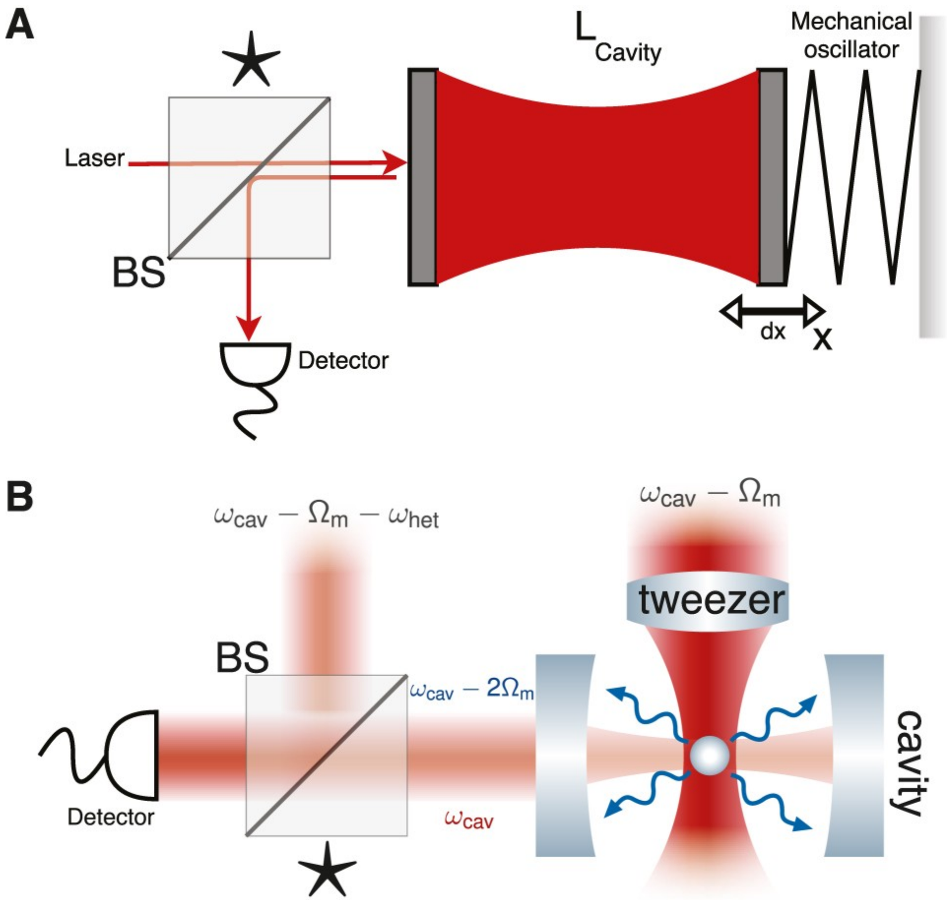
- Quantum gravitational sensing
- Dark matter Quantum sensing
- Stark Localization (Single particle)
- Time evolution of Stark Localization
- Stark Many-body Localization (MBL)
- Time evolution of Stark MBL

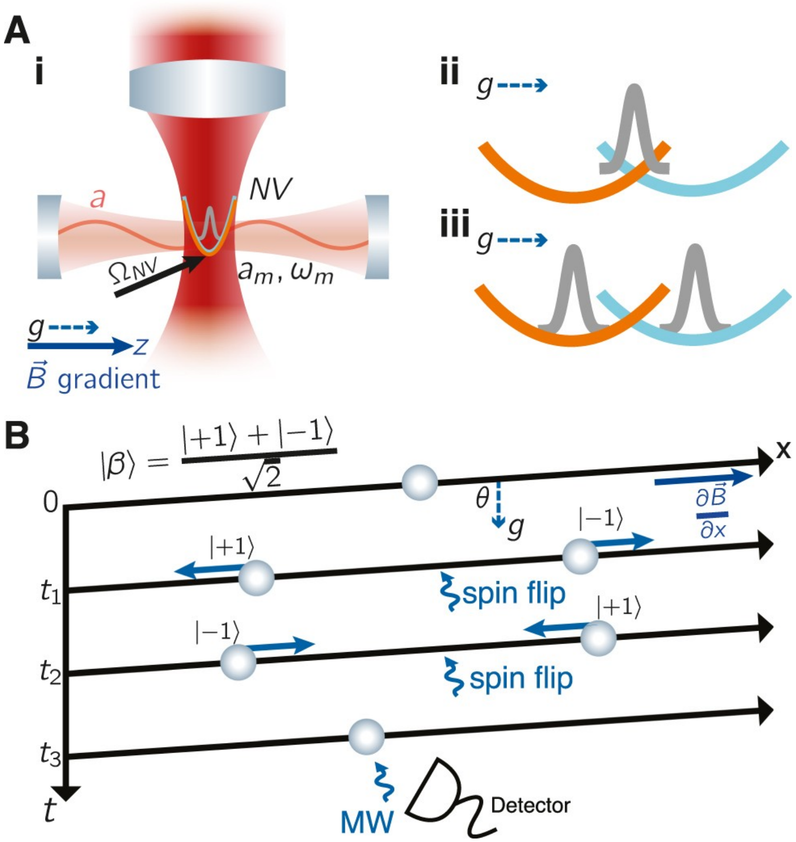
Gravitational quantum sensing



Phys. Rev. Lett. 124, 171102 (2020)

Gravitational quantum sensing

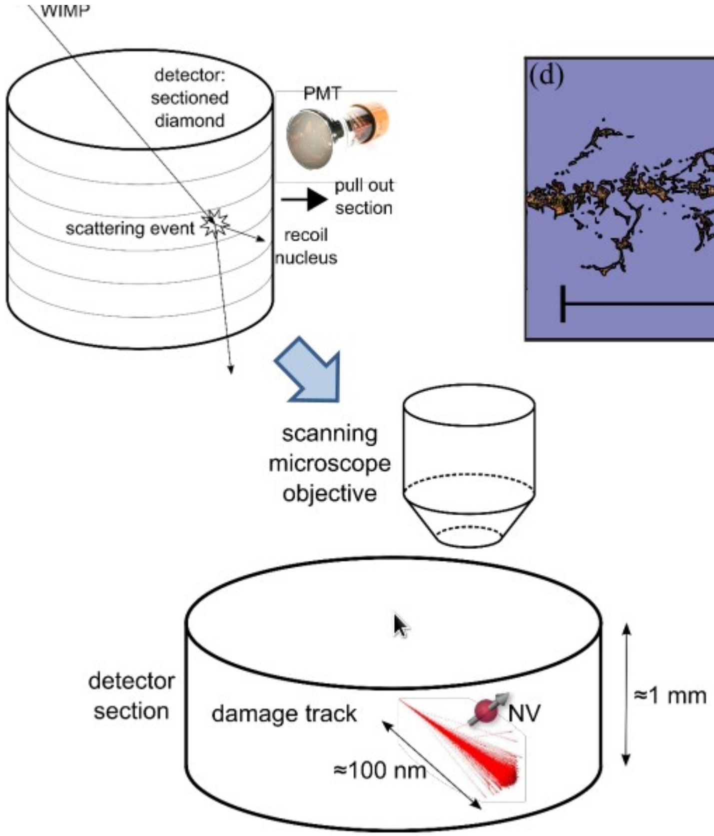


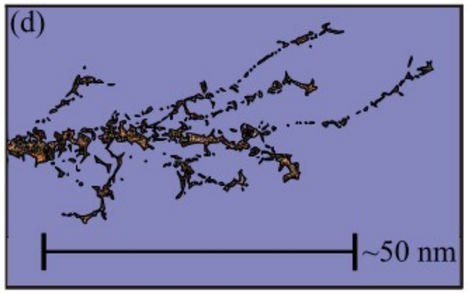


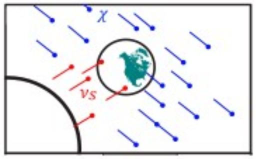
Phys. Rev., vol. 88, 2013, Art no. 033614

Dark matter quantum sensing

particle-like dark matter (eg: WIMPs)
mass ~ 100 GeV





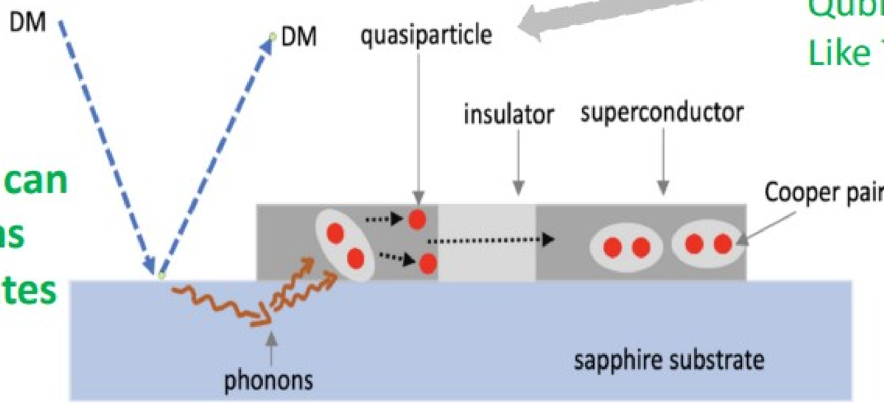


M. Marshall et al. arXiv: 2009.01028; Quantum Sci. Technol. (2021)

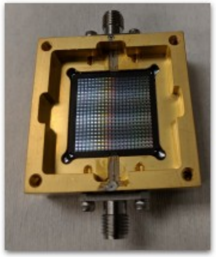
Dark matter quantum sensing

Excess quasiparticle readout using standard Qubit readout protocol Like T_1, T_2 etc.

Particle like DM can excite phonons in qubit substrates

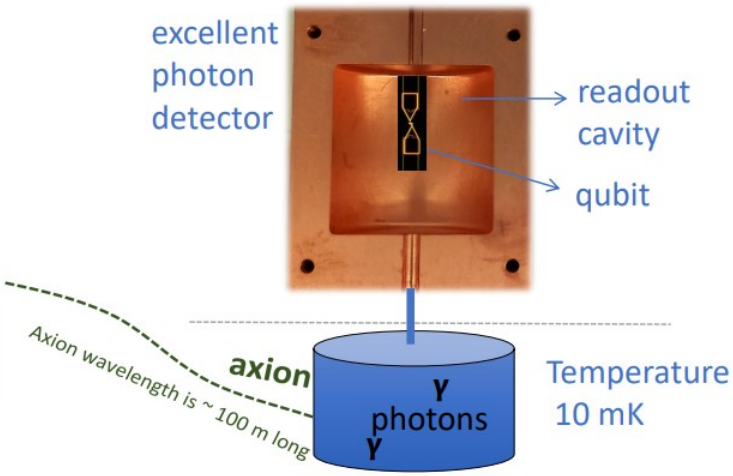


Phonon E ~ 10 to 100 meV



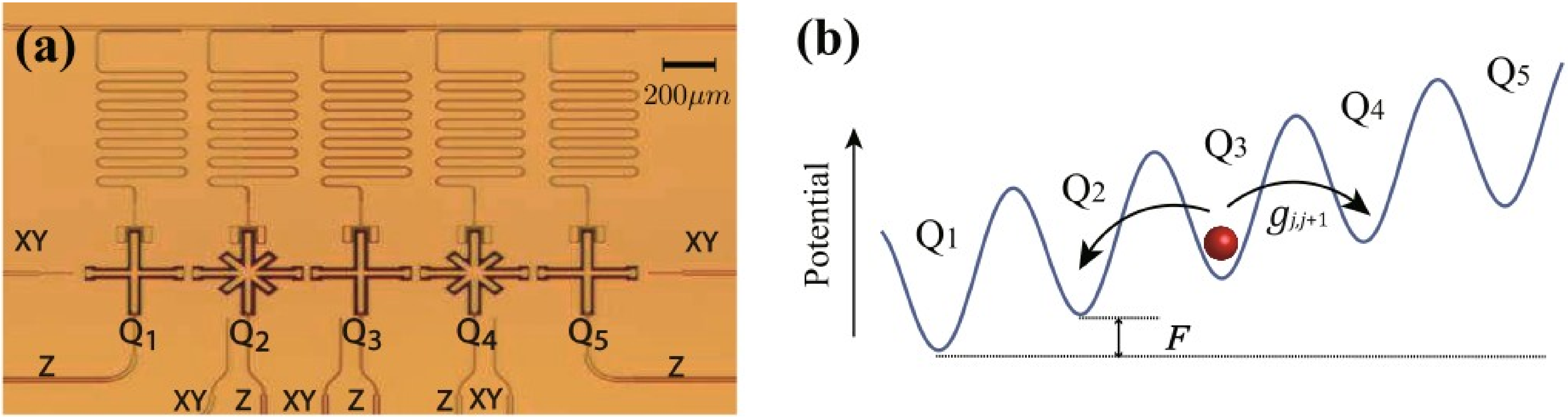
Qubit array

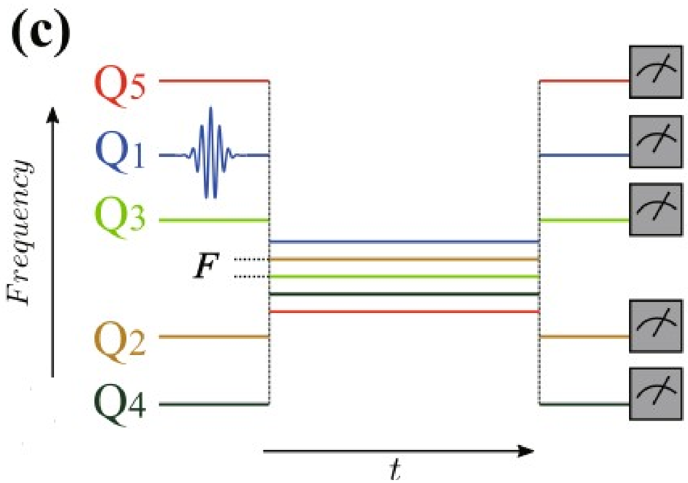
Qubit detector



Nat. Phys. 18, 145–148 (2022)

Wanier-Stark localization

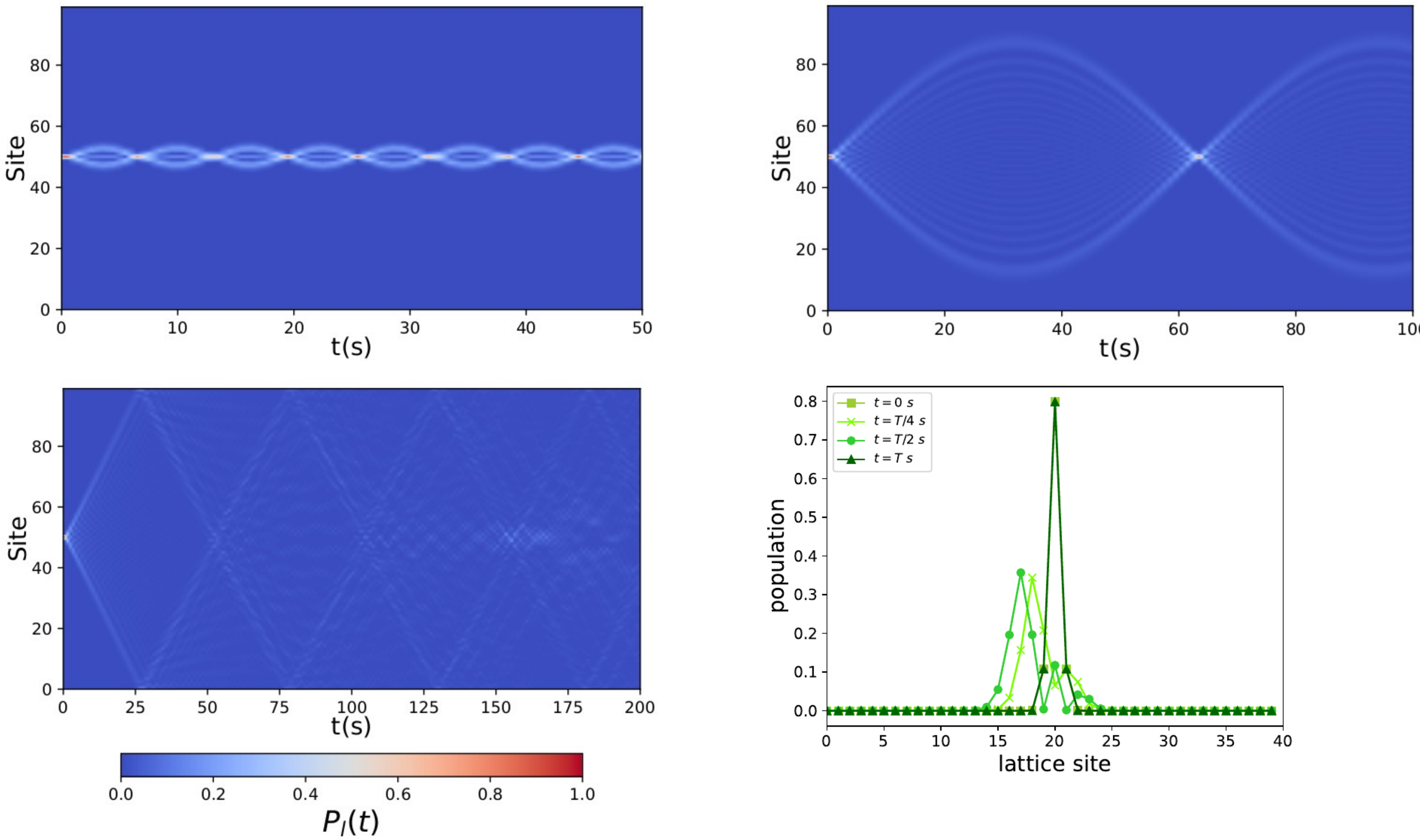




$$H(h) = J\sum_{i=1}^{L-1}\left(|i\rangle\langle i+1| + |i+1\rangle\langle i|\right) + h\sum_{i=1}^{L} i|i\rangle\langle i|$$

Quantum Information volume 7, Article number: 51 (2021)

Wanier-Stark localization



Fidelity and Quantum Fisher Information

$$f(\lambda, \lambda + \delta\lambda) = \langle \psi_0(\lambda) | \psi_0(\lambda + \delta\lambda) \rangle$$

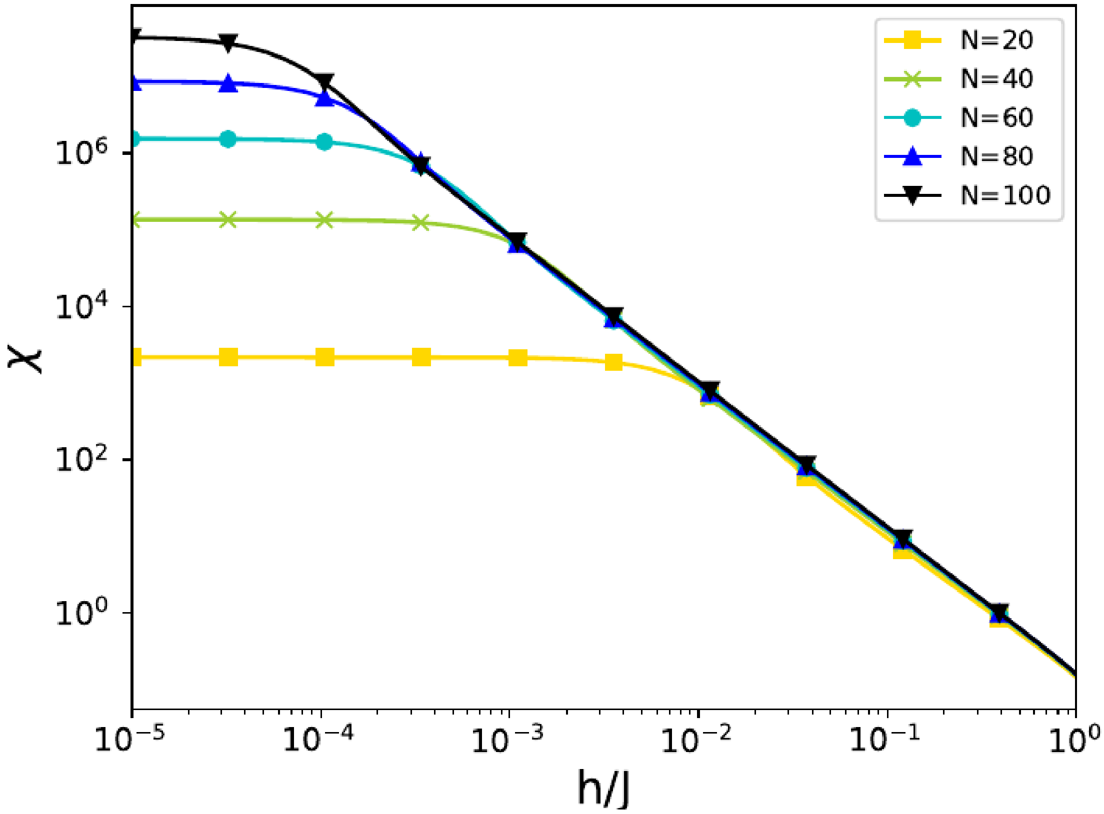
$$f(\lambda, \lambda + \delta\lambda) = 1 - \frac{(\delta\lambda)^2}{2}\chi$$

$$\mathcal{F}_Q \;=\; 4\chi$$

$$\mathcal{F}_Q = 4Re\{\langle \partial_\lambda \psi_0 | \partial_\lambda \psi_0 \rangle - \langle \partial_\lambda \psi_0 | \psi_0 \rangle \langle \psi_0 | \partial_\lambda \psi_0 \rangle\}$$

$$\delta\lambda^2 \;\geq\; 1/(\nu \mathcal{F}_Q)$$

Quantum Fisher Information
Stark localization



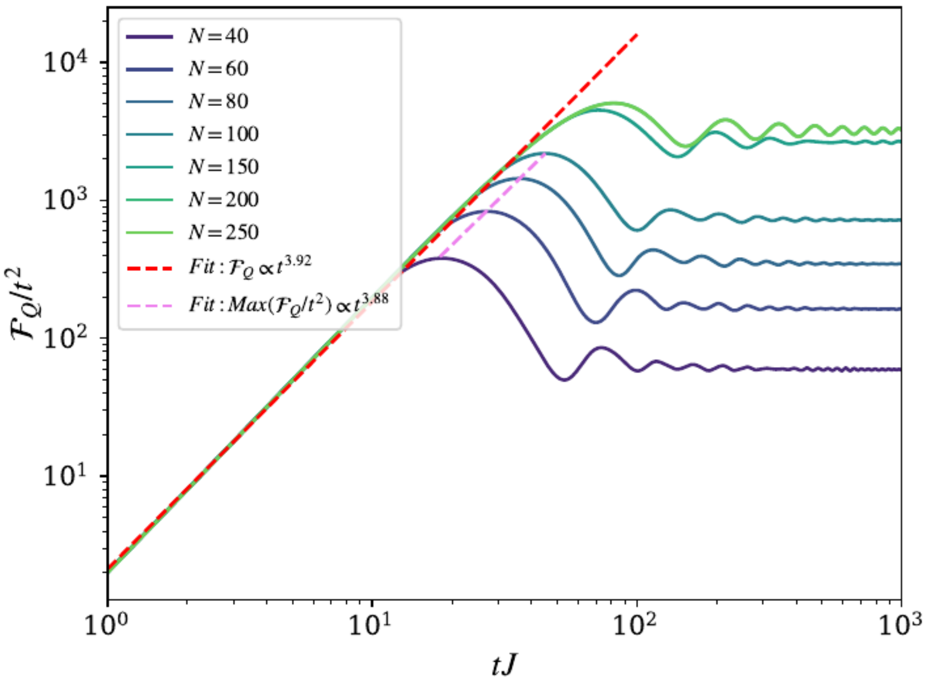
$$|\phi_m\rangle = \sum_{l-m}^{N} J_l\left(\frac{2J}{h_0}\right)|l\rangle$$

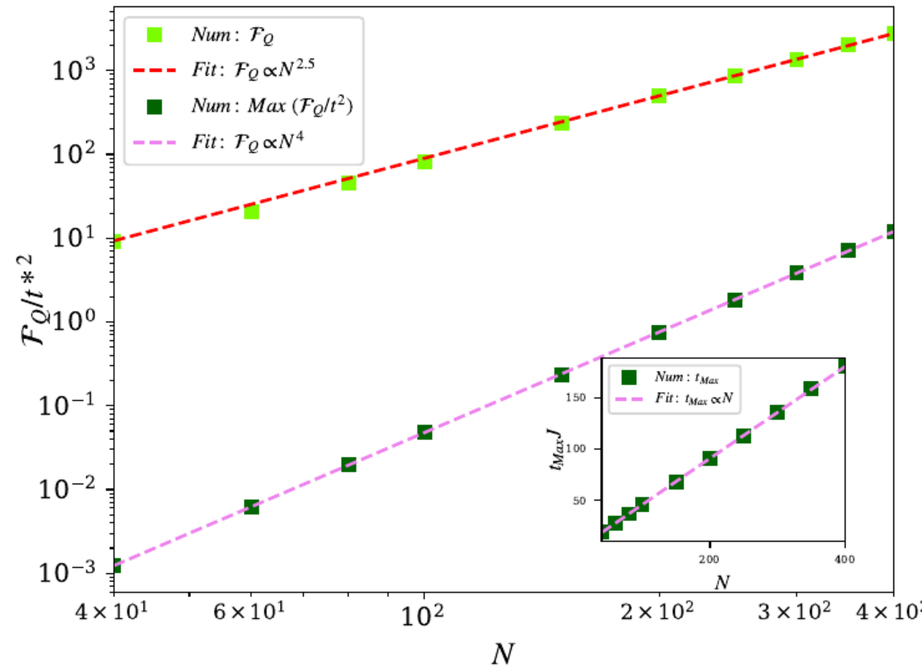
$$K_{l,l'}(t) = \sum_{m=1}^{N} \langle l|\phi_m\rangle \langle \phi_m|l'\rangle \exp(-iE_m t)$$

$$f_l(t) = \sum_{l'=1}^{N} K_{l,l'}(t) f_{l'}(0)$$

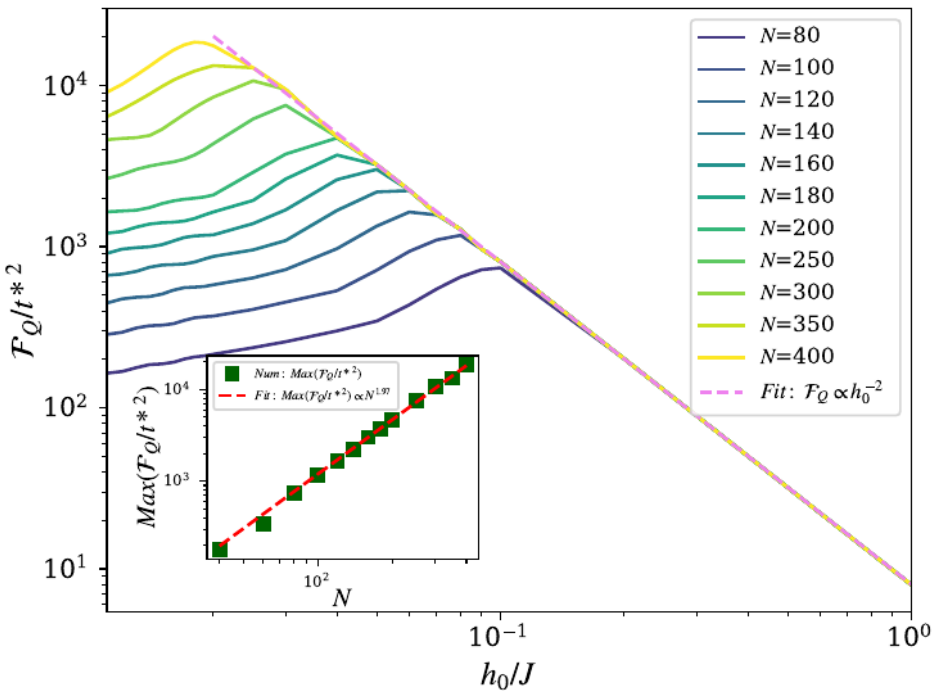
Philosophical Magazine B, 74:2, 105-137

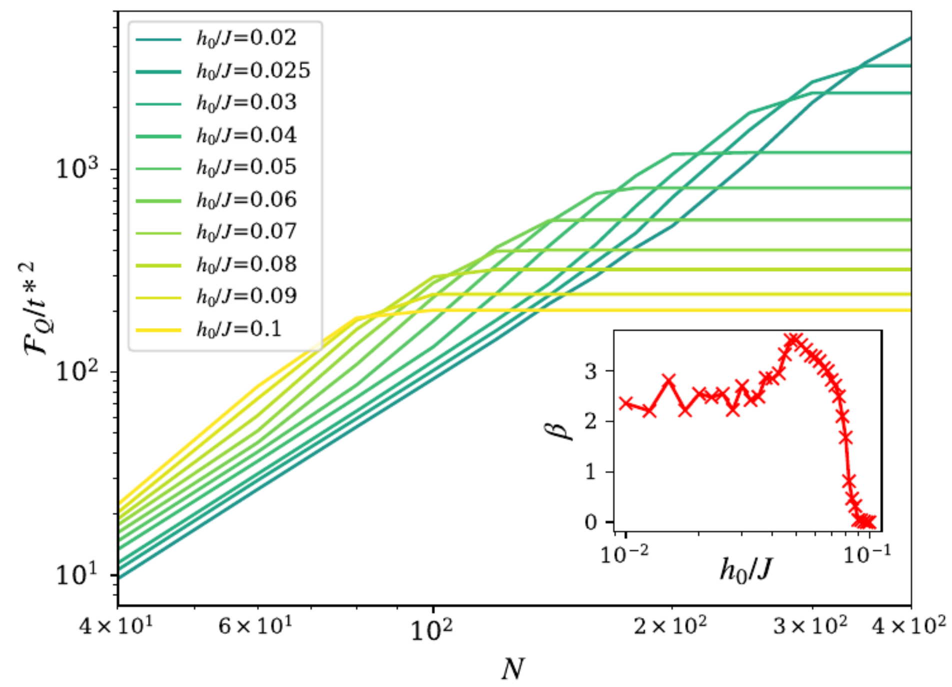
Quantum Fisher Information
Stark localization – Time evolution



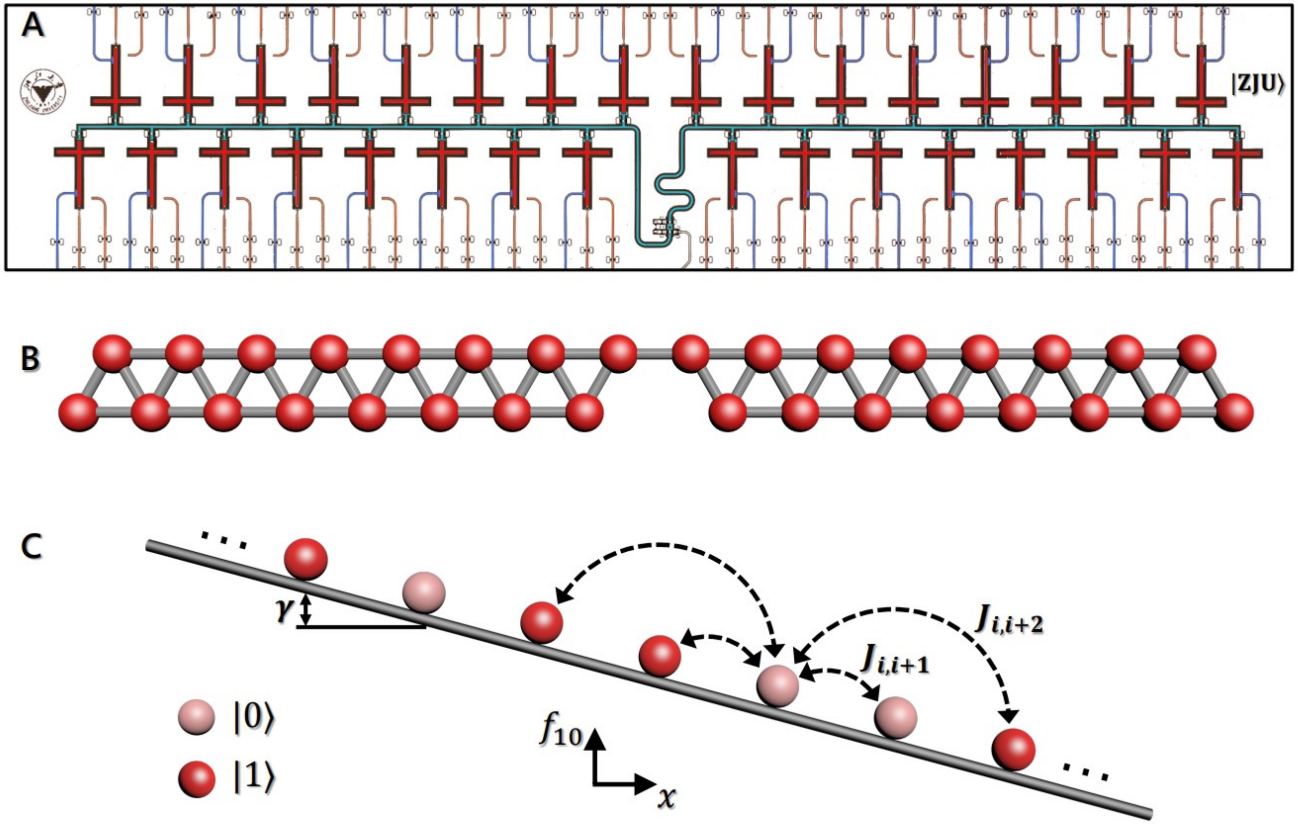


Quantum Fisher Information
Stark localization – Time evolution





Stark many-body localization



$$\frac{H}{\hbar} = -J \sum_{i=1}^{N-1} (\sigma_i^+ \sigma_{i+1}^- + \sigma_i^- \sigma_{i+1}^+) + h_0 \sum_{i=1}^{N} i \sigma_i^+ \sigma_i^-$$

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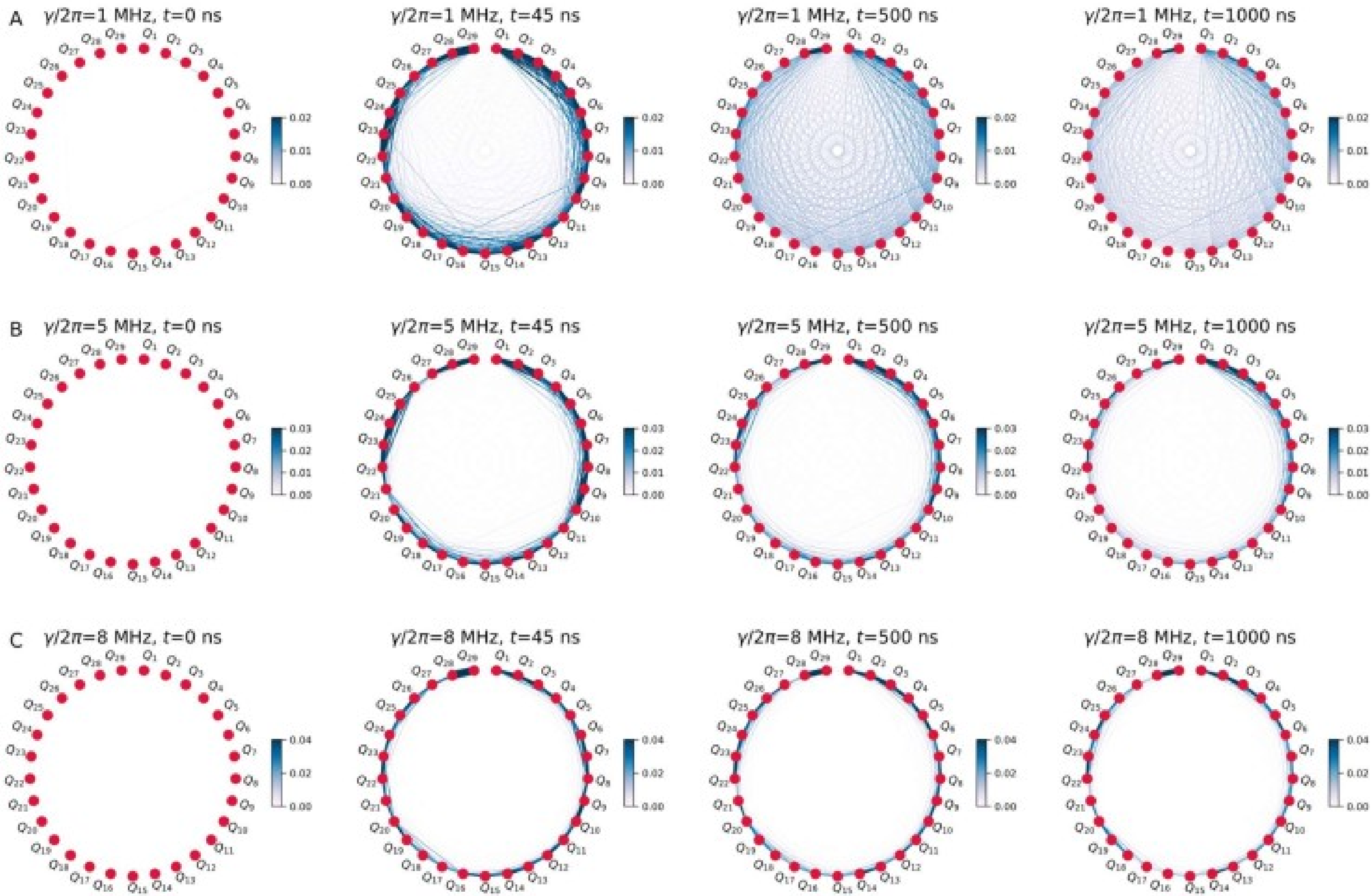
Stark many-body localization
Correlation and QFI



Phys. Rev. Lett. 127, 240502 – Published 10 December 2021

Future Researches

- Adding Dephasing terms
- Apply Gravity field as a Stark Gradient field
- Apply AC field to detect Dynamical localization
- Dark matter as an AC field

$$H(t) \;=\; -J\sum_{l=1}^{N-1} |l\rangle\langle l+1| + |l+1\rangle\langle l| + \;(h_0 + h_1\cos(\omega t))\sum_{l=1}^{N} l\,|l\rangle\langle l|$$

Thank you for your attention