Physics Colloquium, 19.04.21, כ"ב לעומר תשפ"ב

Quantum Simulations using quantum computers on the cloud

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Bar-Ilan University

Dynamics of complex quantum systems

IBM

Eli Arbel
Hagai Landa

Microsoft

Tomer Simon
Eyal Malach
Fabrice Frachon

Eyal Estrin

Inter-University Computation Center

Marcello Calvanese Strinati — Leon Bello — Daniel Azses — Inbar Shani — David Dentelski — Yonatan Saadia — Mor Roses

(December 2019)

http://www.nonequilibrium.org

Financial Support

Bar-Ilan University

Emanuele Dalla Torre

Physics Colloquium 19.04.21

Quantum computing on the cloud **is a reality!**

Portals:

amazon

Microsoft

IBM

Hardware:

D:Wave

rigetti

IONQ

Honeywell

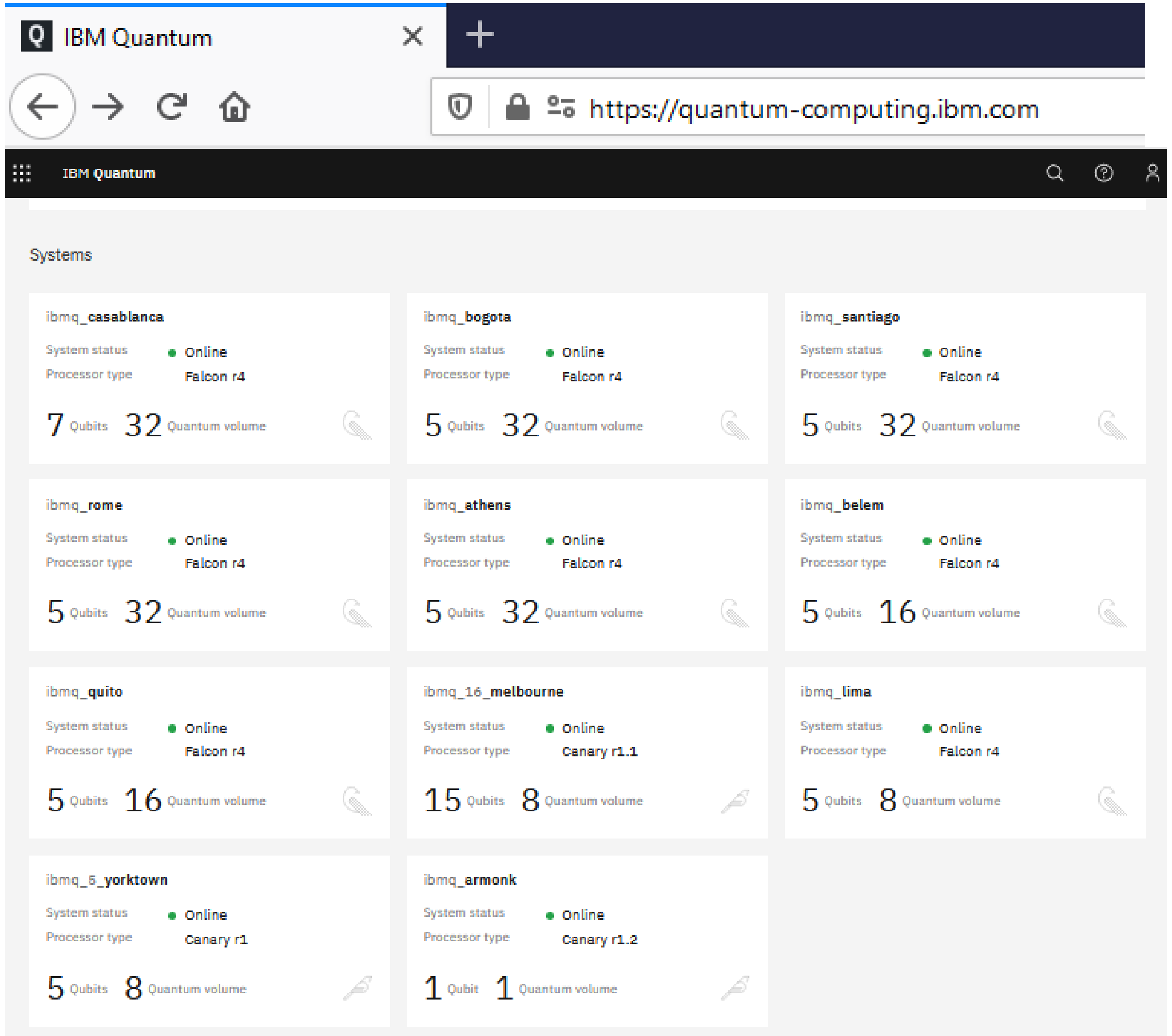
IBM

Not available in Israel

Very expensive

For free

IBM portal


IBM Quantum
https://quantum-computing.ibm.com
IBM Quantum
Systems
ibmq_casablanca
System status Online
Processor type Falcon r4
7 Qubits 32 Quantum volume
ibmq_bogota
System status Online
Processor type Falcon r4
5 Qubits 32 Quantum volume
ibmq_santiago
System status Online
Processor type Falcon r4
5 Qubits 32 Quantum volume
ibmq_rome
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ibmq_athens
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ibmq_belem
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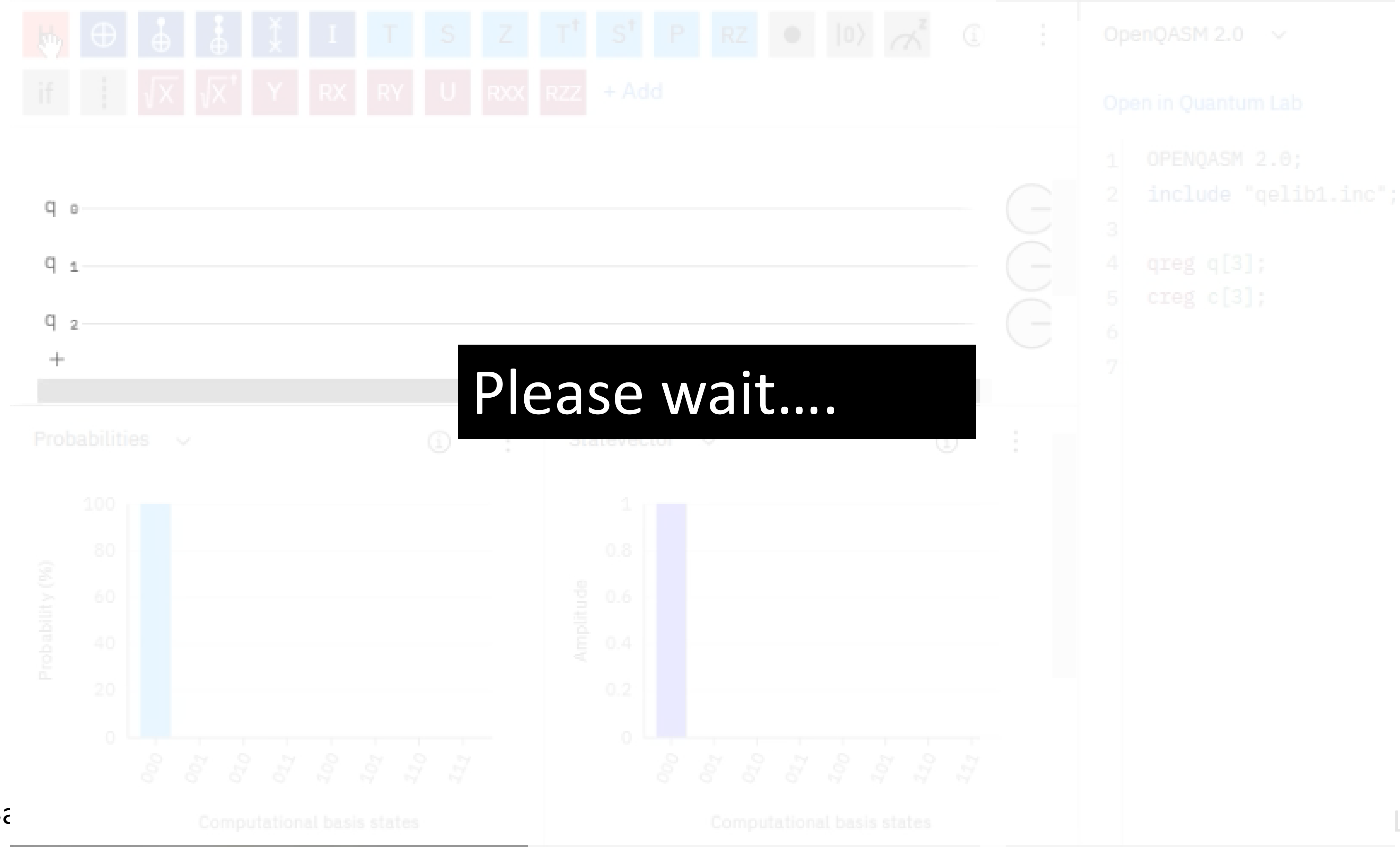
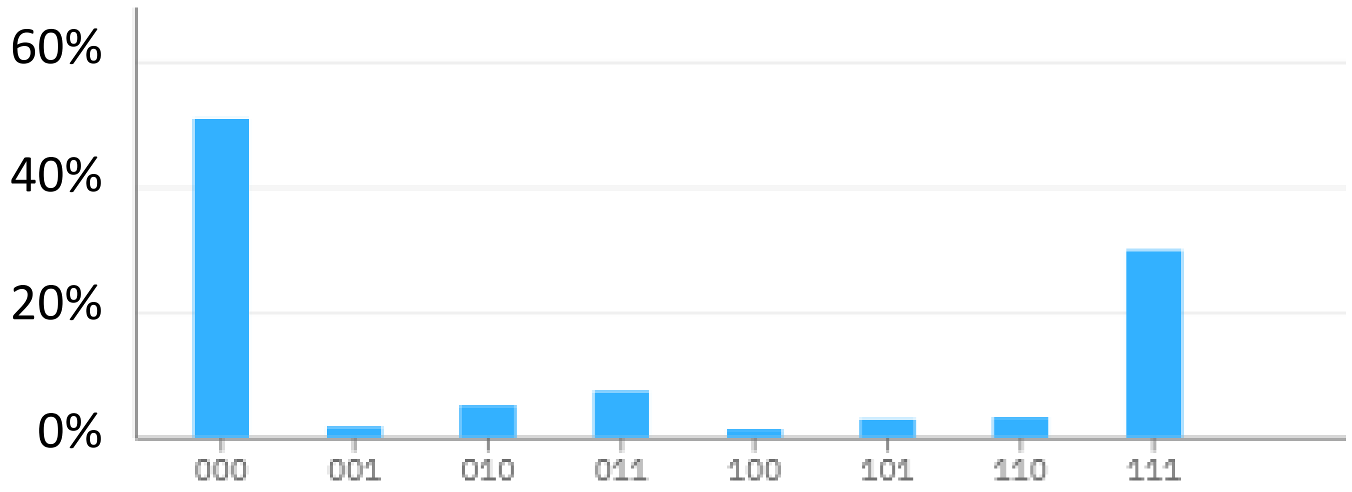
Processor type Falcon r4
5 Qubits 16 Quantum volume
ibmq_quito
System status Online
Processor type Falcon r4
5 Qubits 16 Quantum volume
ibmq_16_melbourne
System status Online
Processor type Canary r1.1
15 Qubits 8 Quantum volume
ibmq_lima
System status Online
Processor type Falcon r4
5 Qubits 8 Quantum volume
ibmq_5_yorktown
System status Online
Processor type Canary r1
5 Qubits 8 Quantum volume
ibmq_armonk
System status Online
Processor type Canary r1.2
1 Qubit 1 Quantum volume

Cat state preparation



Please wait....

Cat state preparation



Gate error = 4%
Measurement error = 3%

→ Error per qubit = 7%

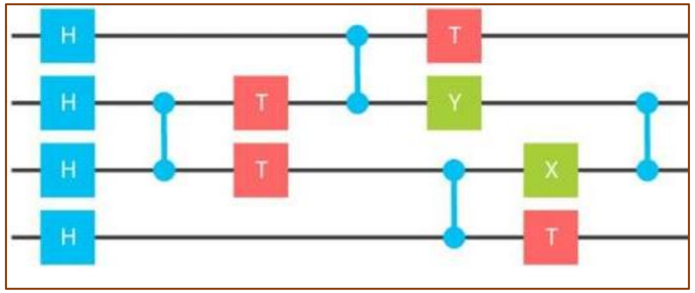
Number of qubits: 3 → 14 → 100

Cumulative error: $0.93^3 = 80\%$ | $0.91^{14} = 36\%$ | $0.91^{100} = 0.07\%$

The main challenge

Model :

Unitary quantum computer



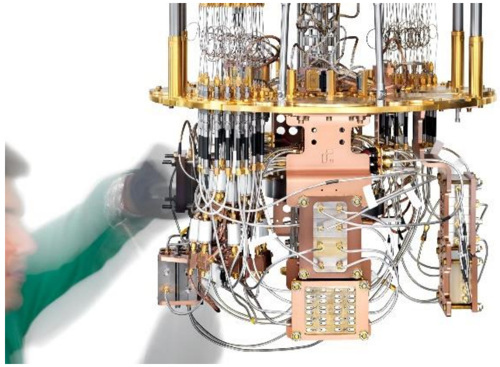
f.e. Shor algorithm (breaks RSA),
quantum machine learning

quantum error correction

open quantum systems

Reality :

Noisy superconducting circuits

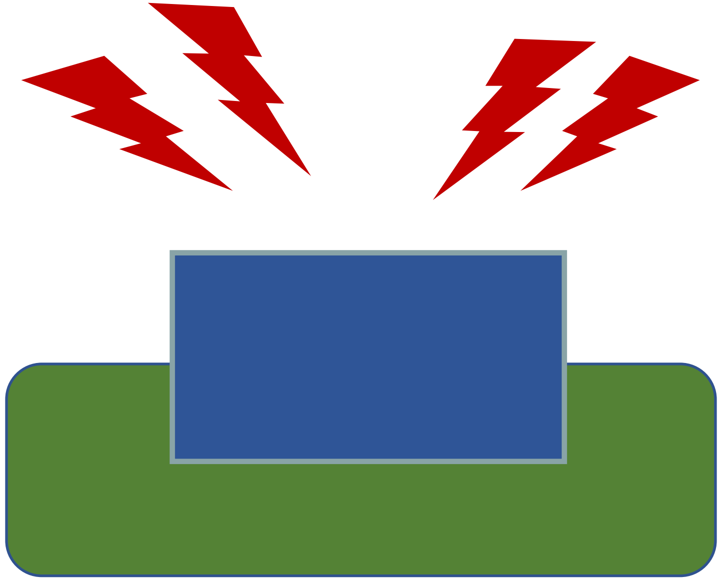


Many-body open quantum systems

Time dependent drive

Quantum system

Dissipative bath



1. Periodic drives
[Mor Roses, Hagai Landa (IBM)]
arXiv:2102.09590

Periodically driven single qubit

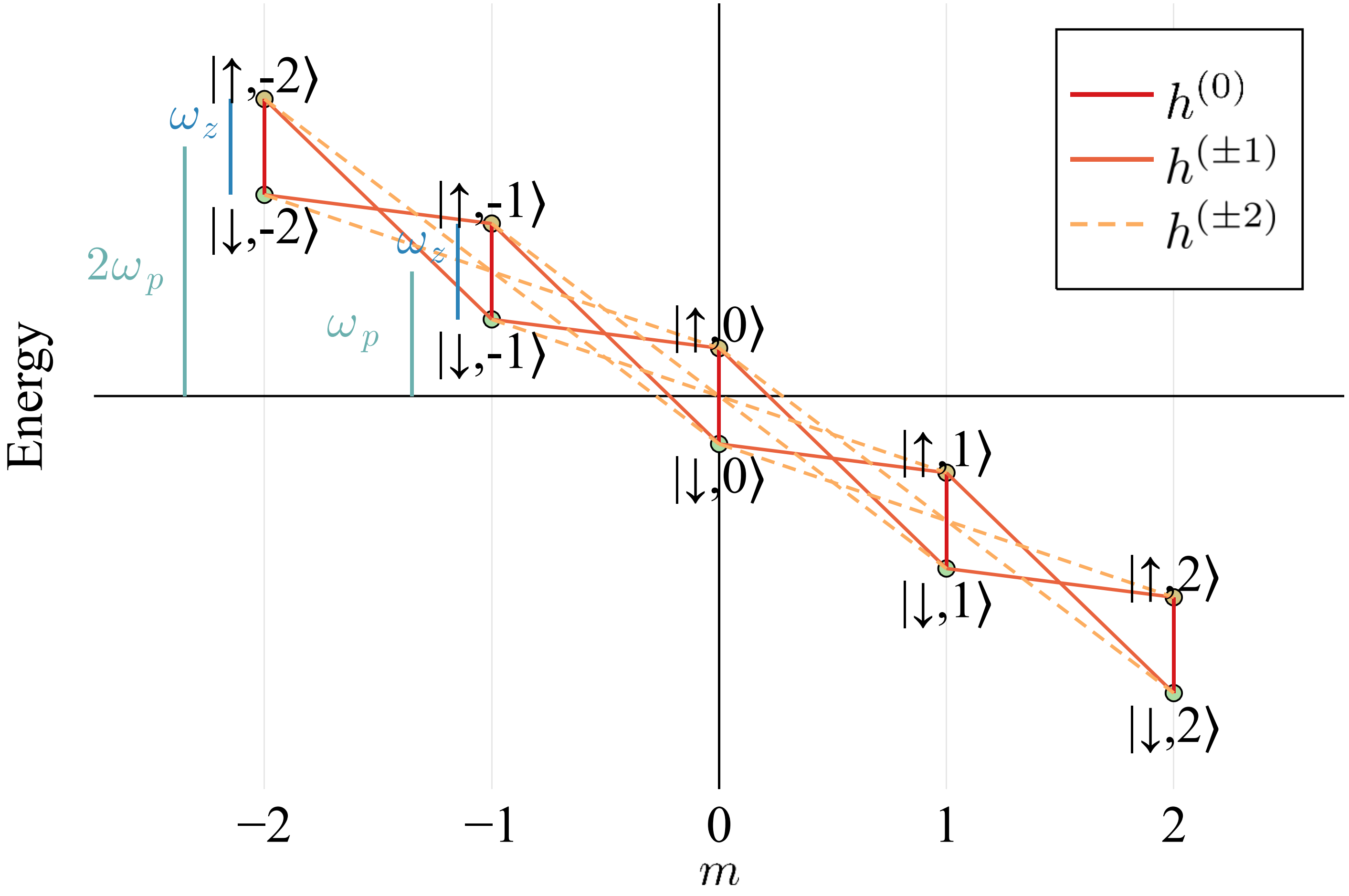
Ingredients:

Pulse engineering:

$$H(t) = \omega_z \sigma^z + h(t)\sigma^x$$

Periodic drive (Floquet)

$$h(t+\tau) = h(t)$$



Floquet engineering

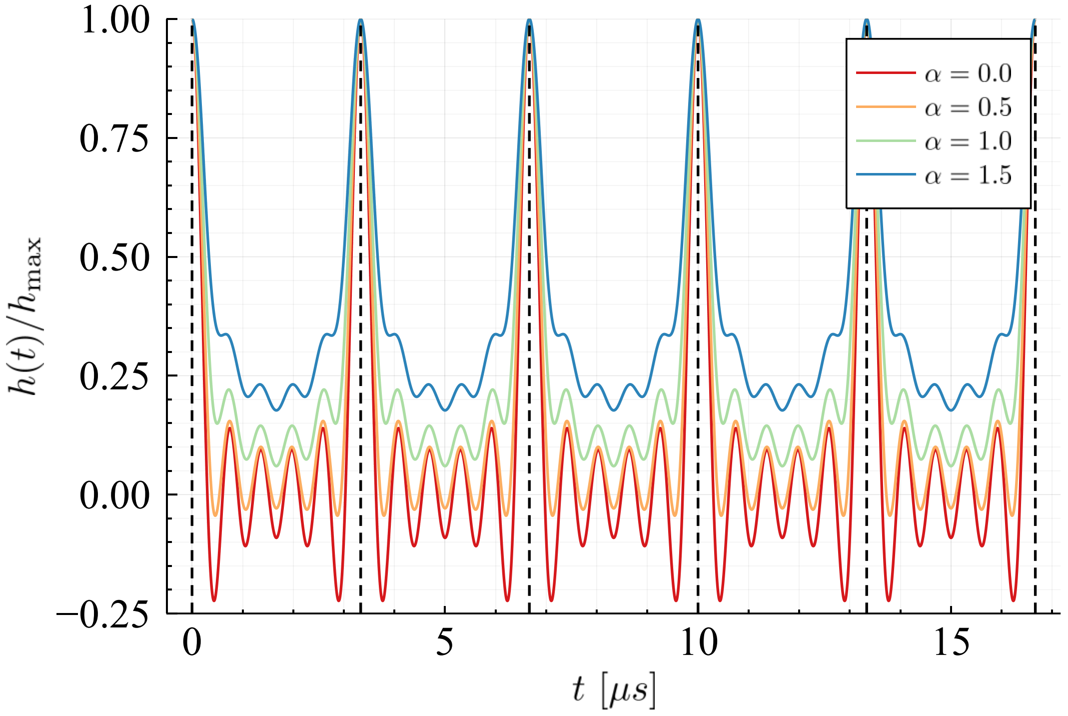
Long ranged coupling:

$$h^{(m)} = \frac{h_0}{(1+|m|)^{\alpha}}$$

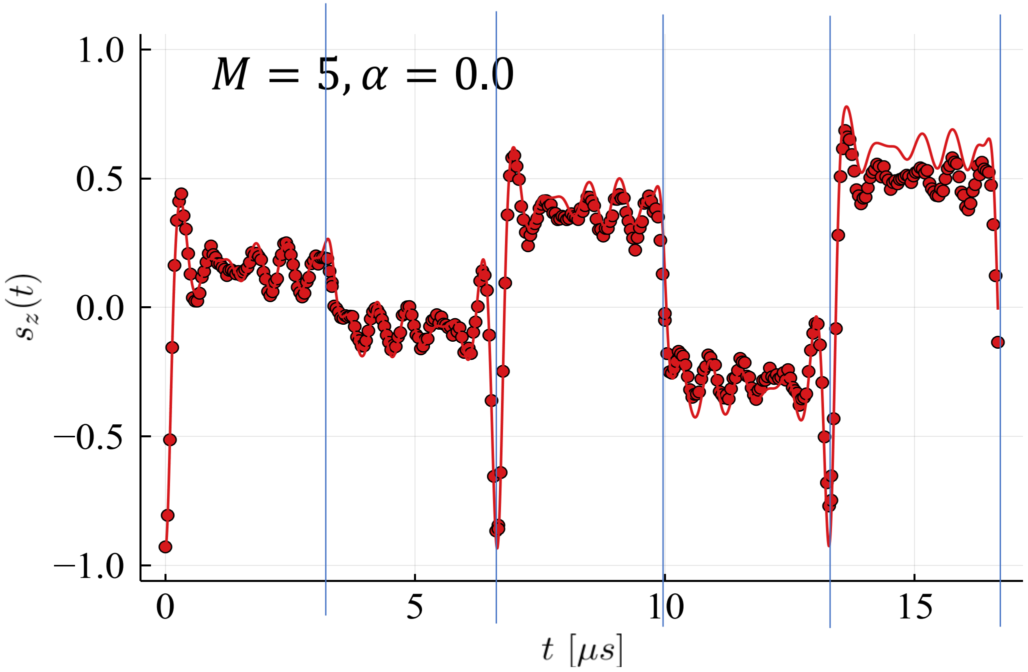
Simulation of gravitational models &

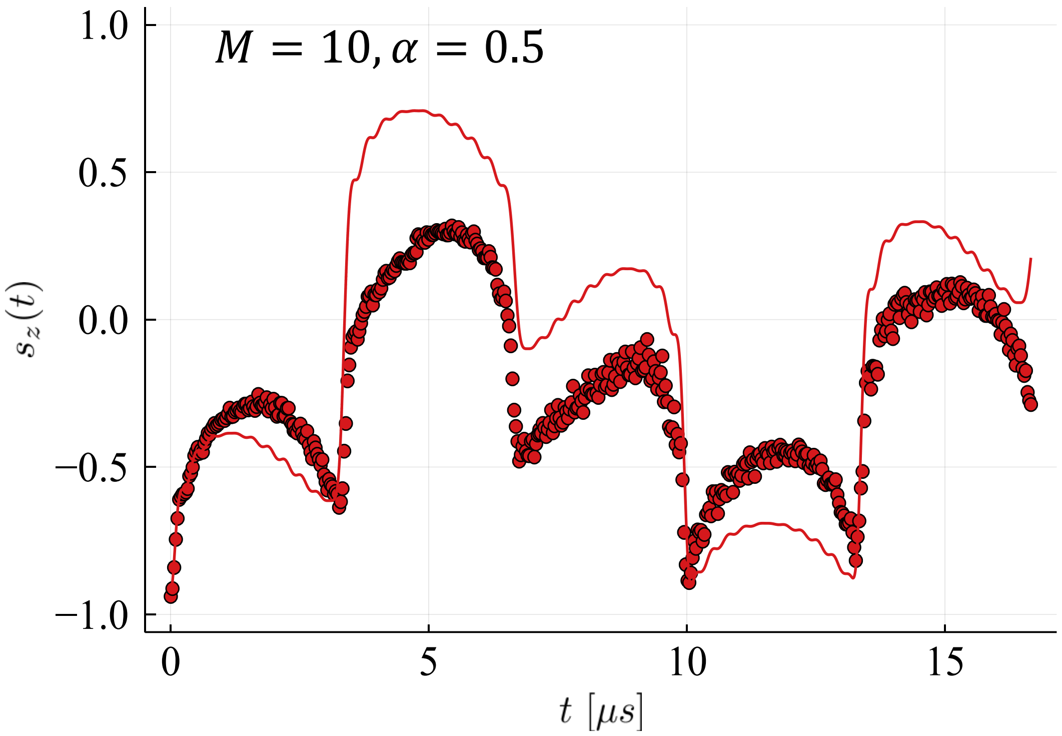
unscreened Coloumb forces ($\alpha = 1$)!

M=5



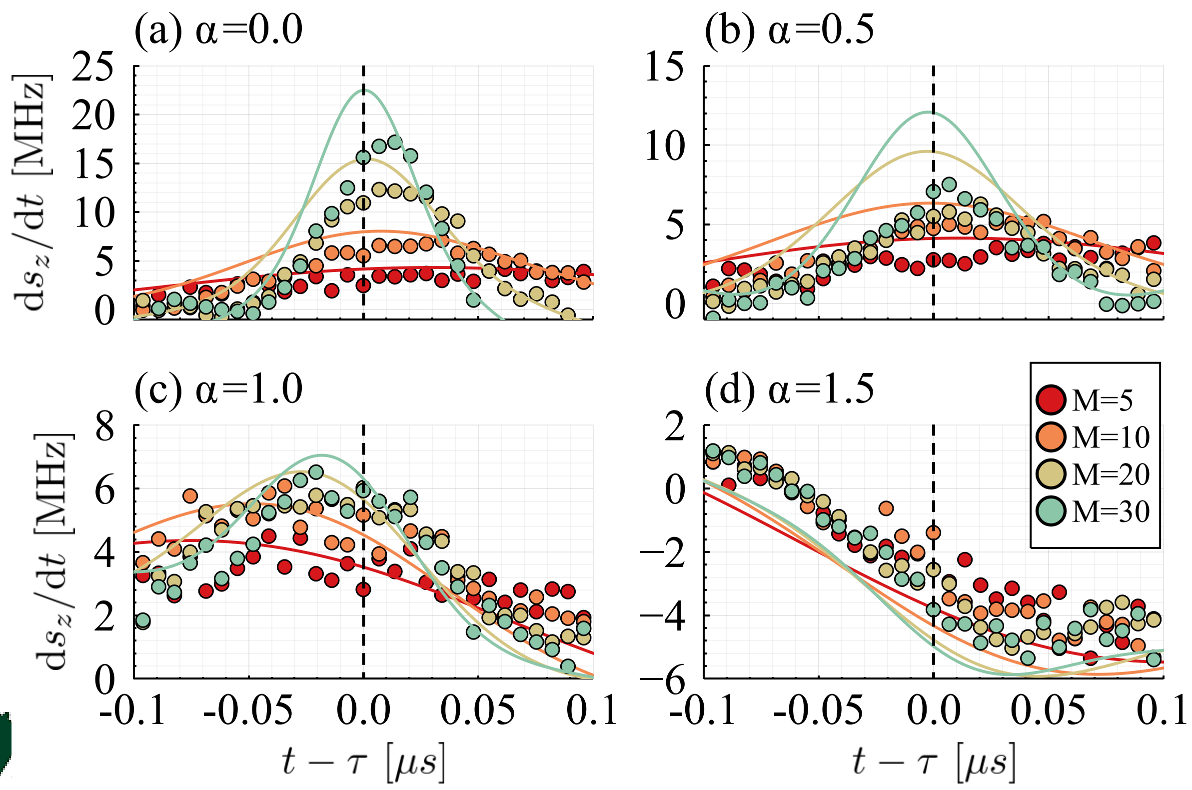
Result from a physical device



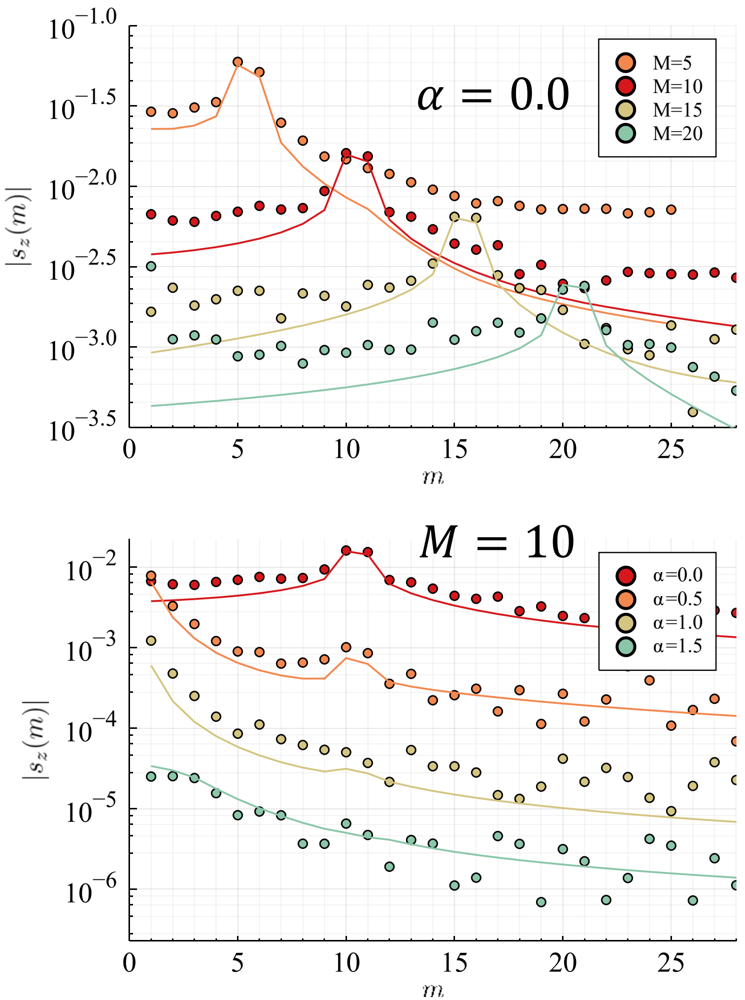


Transition from short range to long range

1) Time derivatives: $\frac{ds_z}{dt}(t=\tau) \sim \sum_m \frac{1}{m^\alpha}$



2) Long tails of the eigenstates:



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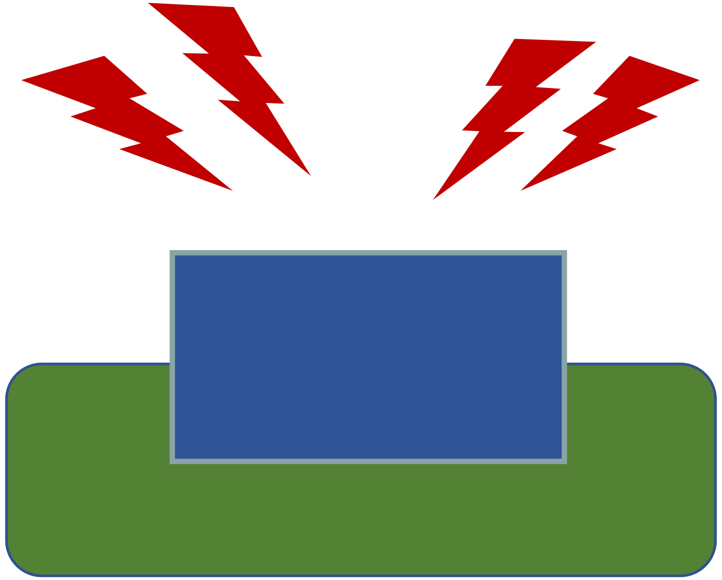


1. Periodic drives

Mor Roses (BIU), Hagai Landa (IBM)
arXiv:2102.09590

2. Topological phases

Daniel Azses (BIU), Yehuda Naveh (IBM),
R. Haenel & R. Raussendorf (Vancouver),
Eran Sela (TAU)
arXiv:2002.04620 (PRL, 2020)

Quantum phases of matter

Ordered

0	1	0	1	0	1	0	1

Disordered

0	1	1	0	0	1	0	1

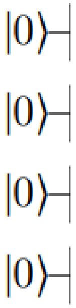
Topological

0	1	1	0	0	0	1	1	0

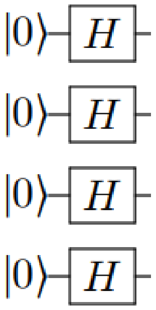
Haldane (1982), AKLT (1987), den Nijs&Rommelse (1989), Dalla Torre,Berg&Altman (2006), ….

Topological phases of matter

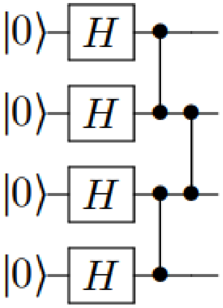
Ordered: Ising coupling



Disordered: Magnetic field



Topological: cluster model



Bat-el Friedman, Atar … 2019) and ref. therein

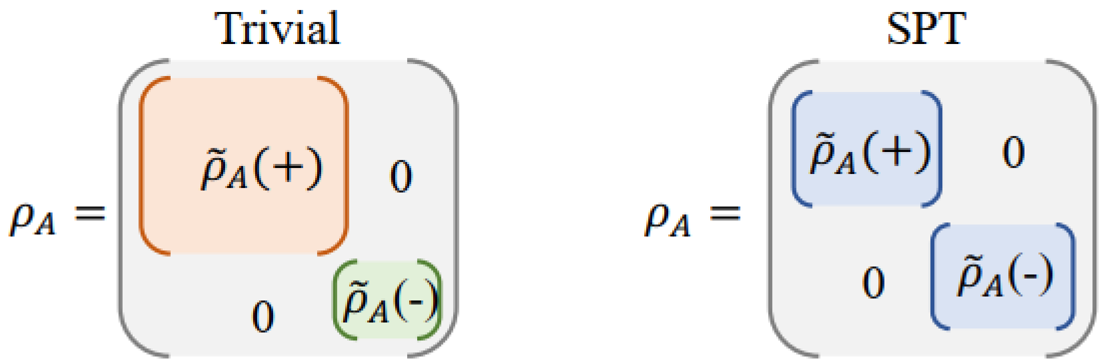
Symmetry resolved topological (SPT) phases

Pollmann-Turner-Berg-Oshikawa (2011), Chen-Gu-Liu-Wen (2012)

Symmetry $\rightarrow G\,|\psi\rangle = g|\psi\rangle \rightarrow [G, \rho_A] = 0$

Symmetry resolved

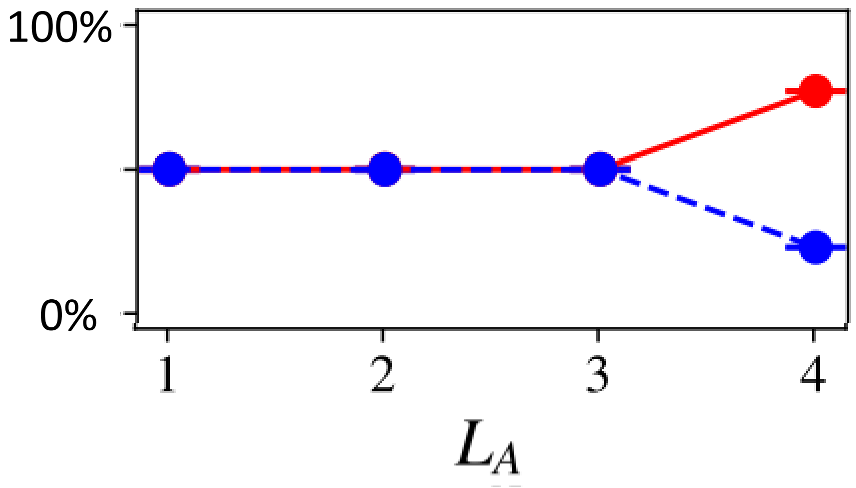
reduced density matrix:



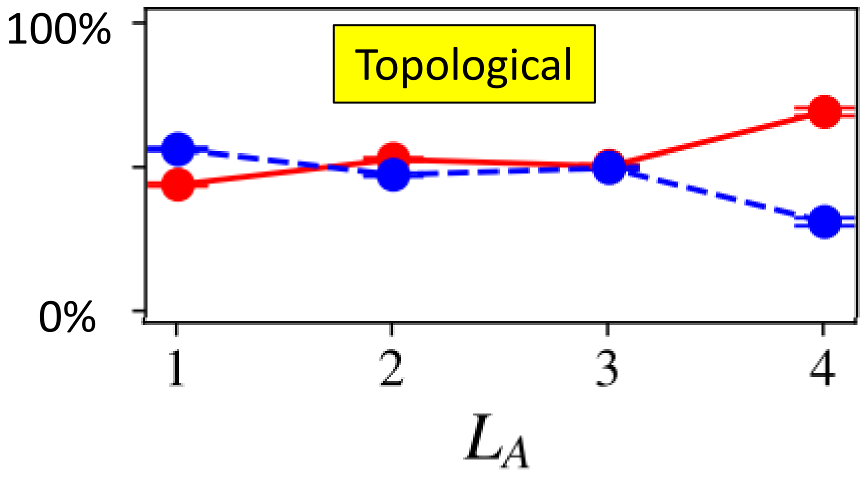
Goldstein & Sela (PRL, 2018)

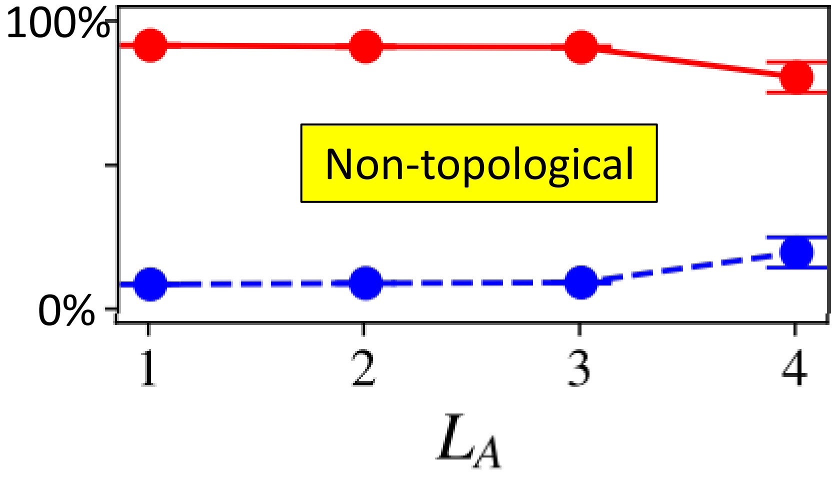
Identifying a topological phases

Simulation



Experiment





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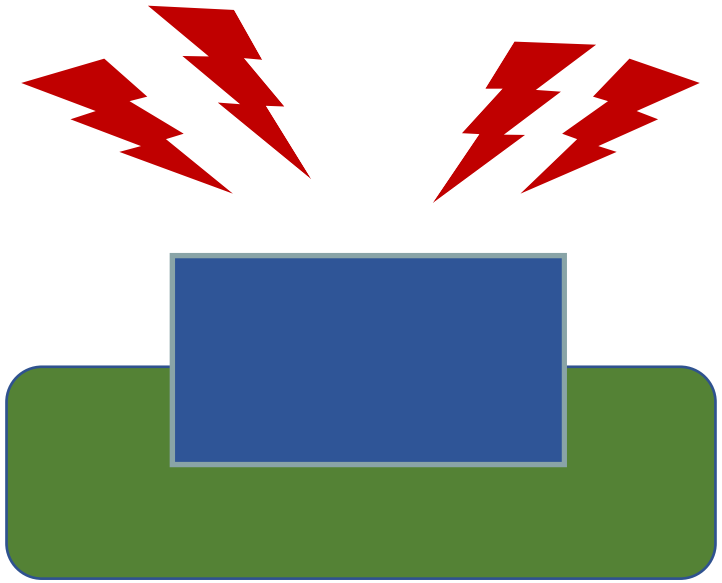

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3. Error mitigation
Meron Shefer, Frima Kalyuzhner, D. Azses, Adi Makmal, IBM, Microsoft, Amazon

Quantum Computing Workshop 2021

Conference Agenda

19.4.2021

14:00-17:00	**Intro to Quantum Computing** Vincent van Wingerden - Technical Architect, MTC, Microsoft Netherlands
17:00-17:35	**Practice on Katas**
17:35-17:45	**Welcome & Introduction** Dr. Tomer Simon – Chief Scientist, Microsoft Israel R&D Center
17:45-18:00	**Keynote** Prof. Stephen Jordan - Principal Researcher, Azure Quantum
18:00-20:30	**Introduction to Q# and QDK** Mariia Mykhailova – Senior Software Engineer, Azure Quantum

20.4.2021

14:00-14:30	**Libraries Overview** Dr. Mathias Soeken - Senior Software Engineer, Azure Quantum
14:30-15:00	**Simulators** Dr. Mathias Soeken - Senior Software Engineer, Azure Quantum
15:00-16:00	**Resource Estimation/Program Validation** Dr. Mathias Soeken - Senior Software Engineer, Azure Quantum
16:00-16:30	**Break**
16:30-17:10	**Optimization - Intro and Deep Dive** Delbert Murphy – Principal Cloud Solution Architect, Microsoft Manufacturing
17:10-17:40	**Future-Proofing your Quantum Development with Q# and QIR** Stefan Wernli - Senior Software Engineer, Azure Quantum
17:40-18:10	**Break**
18:10-20:00	**Azure Quantum - Live Demo** Stefan Wernli - Senior Software Engineer, Azure Quantum

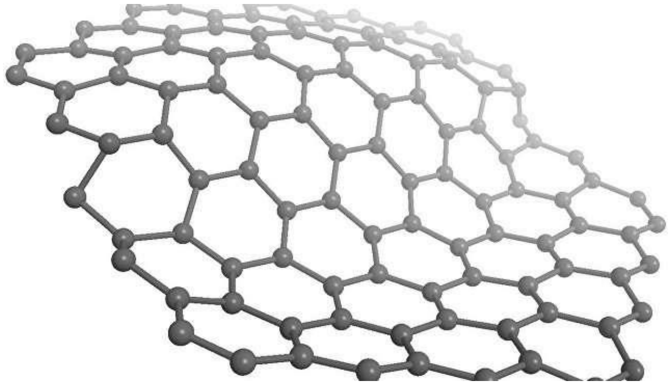
Microsoft

https://forms.office.com/r/YTd3pdC9Km

Summary: Quantum simulations

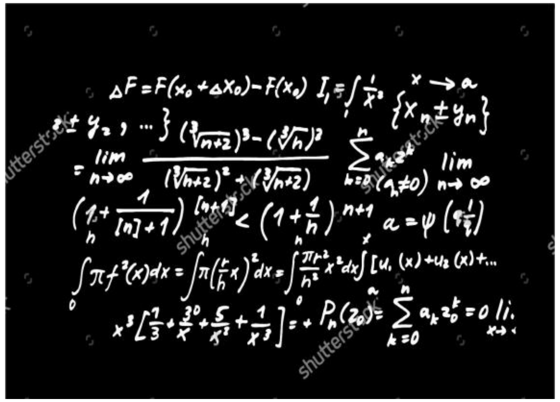
Quantum molecules/material

Size of Hilbert space = 2^{N_A}

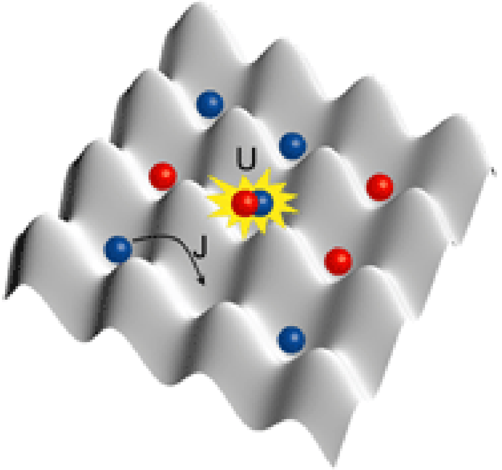


Classical supercomputers

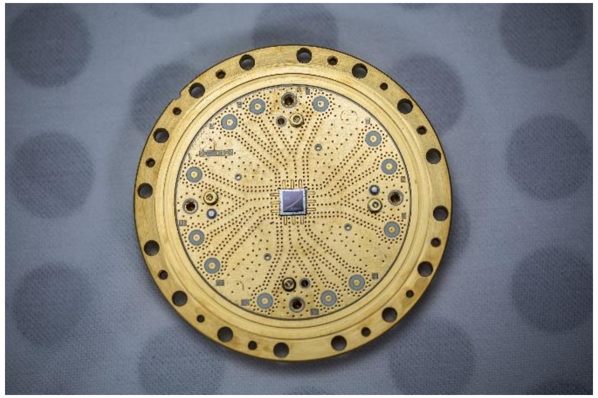
Quantum field theories



Ultracold atoms



Quantum computer on the cloud



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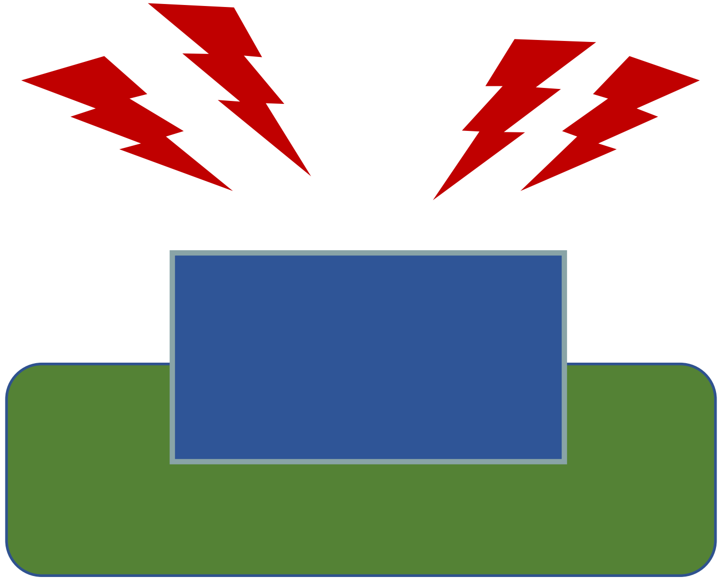

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