Unmasked workshop – Merom Golan – 11/05/2021

Quantum Simulations using quantum computers on the cloud

Emanuele Dalla Torre

Bar-Ilan University

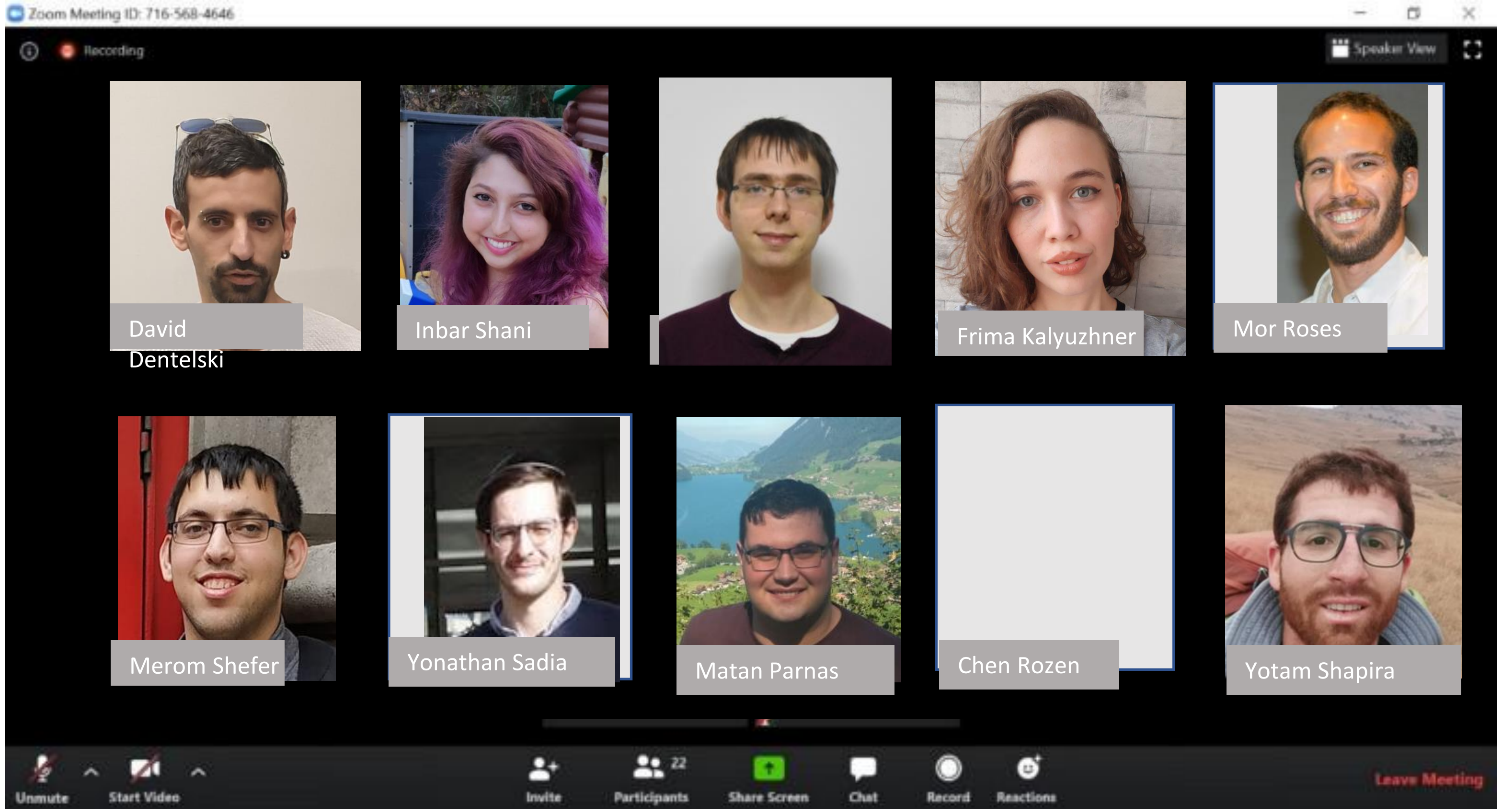
Dynamics of complex quantum systems

Eli Arbel
Hagai Landa

Tomer Simon
Eyal Malach
Fabrice Frachon

Inter-University Computation Center

Eyal Estrin



Financial Support

http://www.nonequilibrium.org

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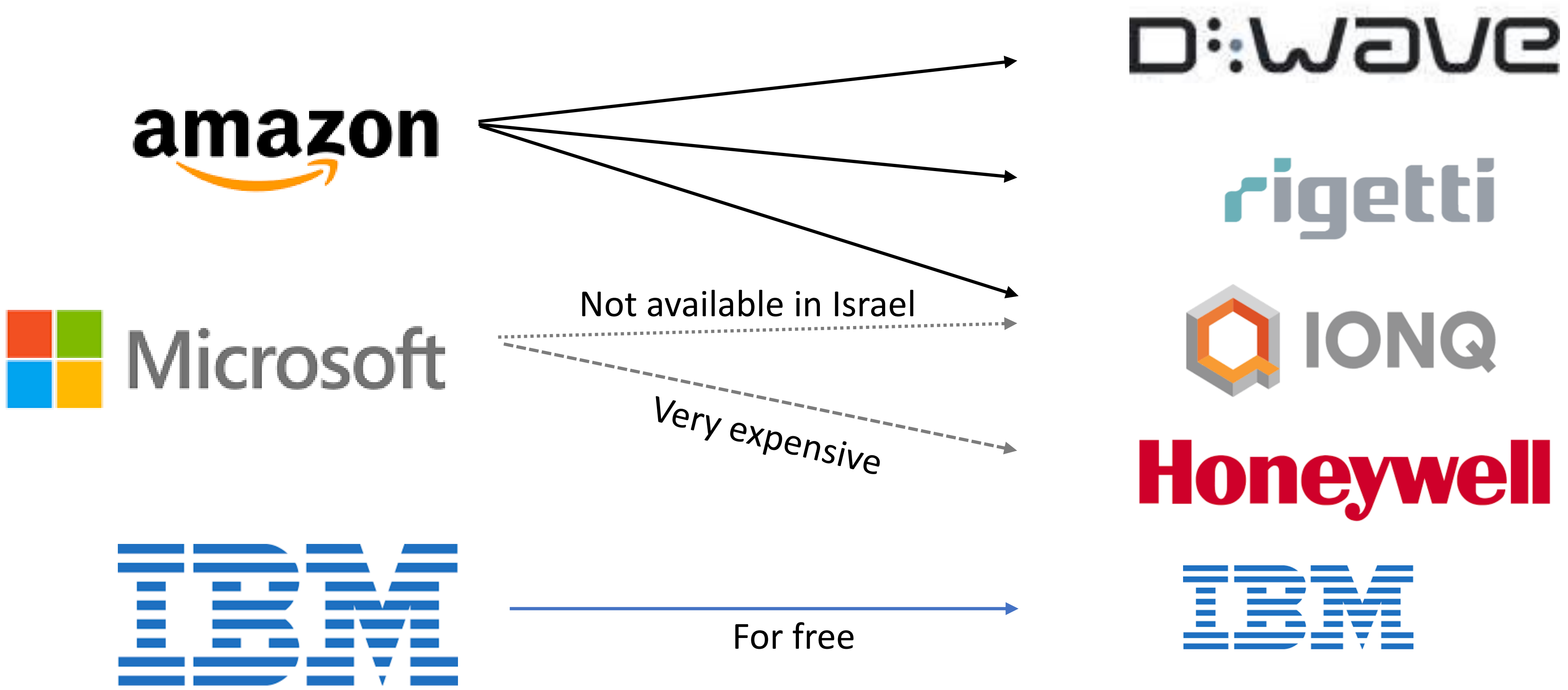
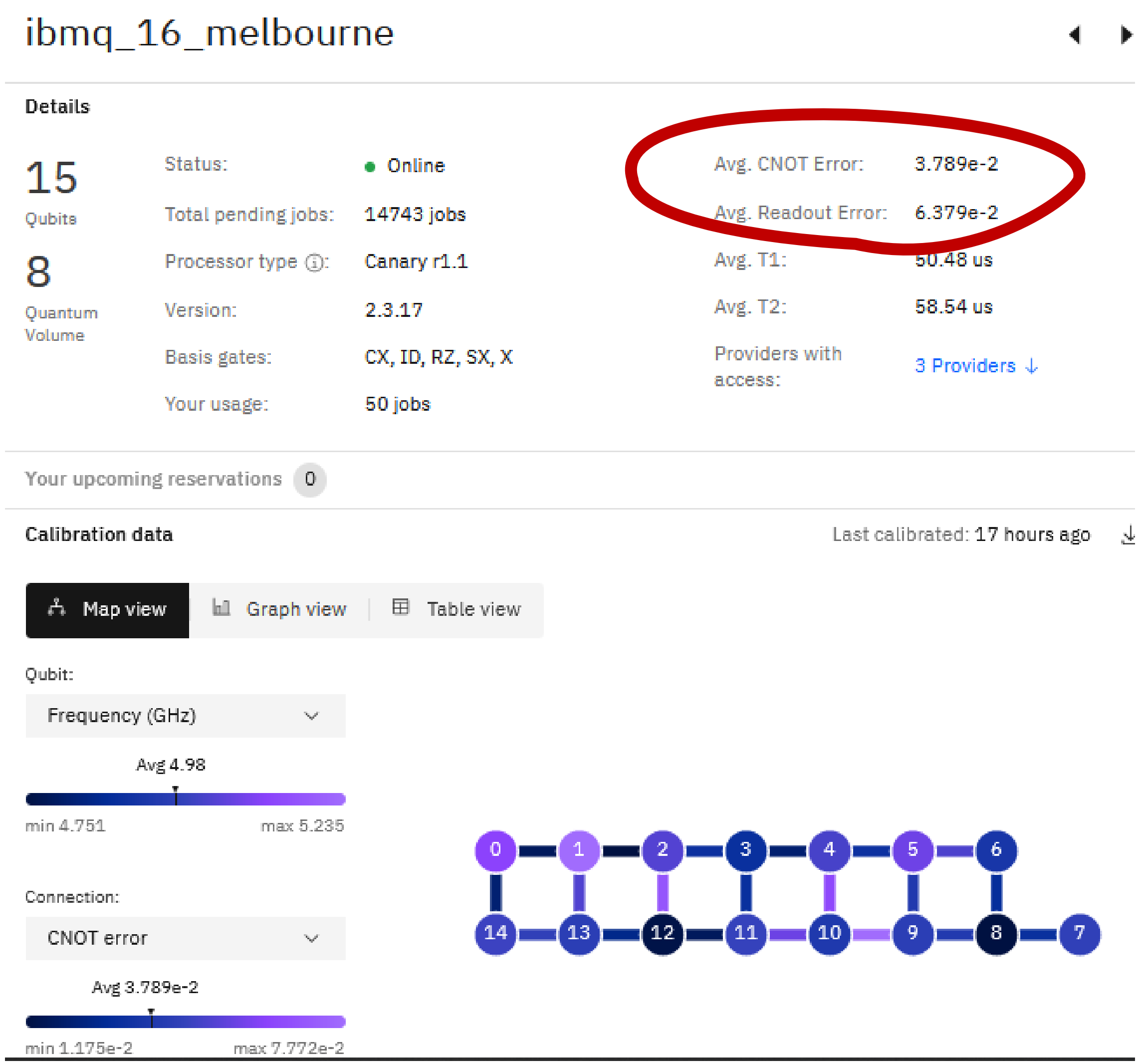
Quantum computing on the cloud **is a reality!**

Portals: **Hardware:**



http://quantum-computing.ibm.com



Cat state preparation

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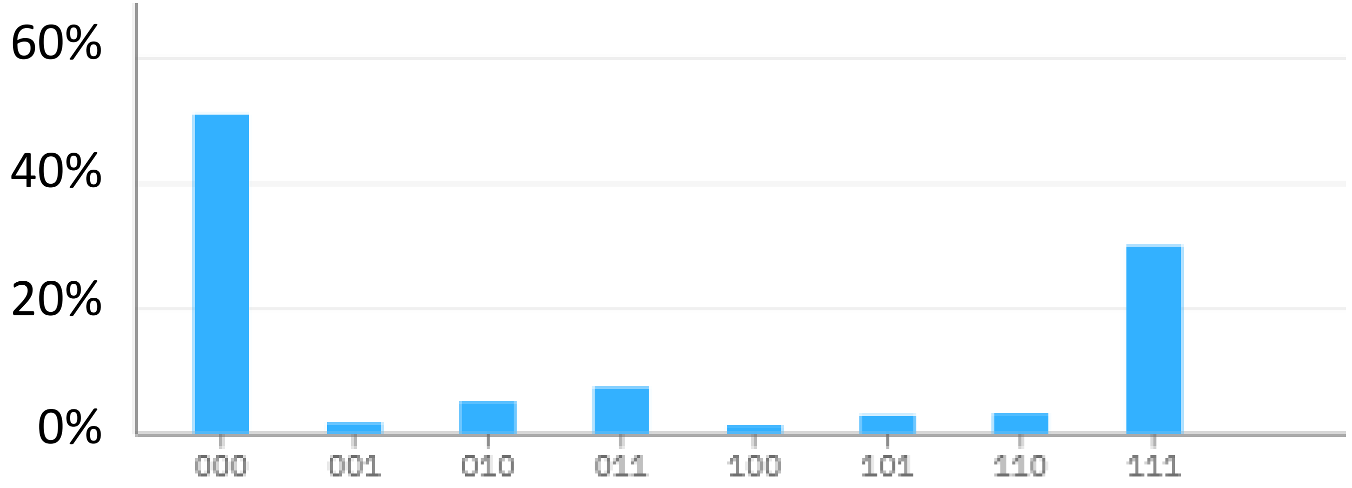


Demonstration of Shor's factoring algorithm for N=21 on IBM quantum processors

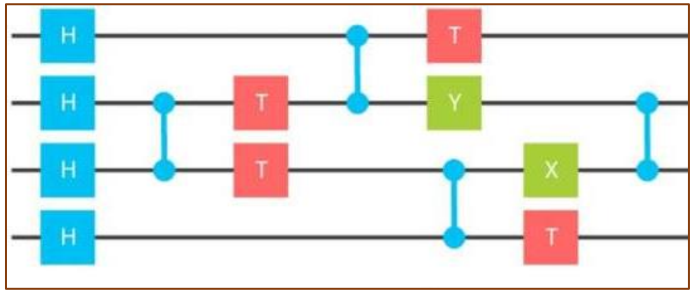
Unathi Skosana and Mark Tame*
Department of Physics, Stellenbosch University, Matieland 7602, South Africa
(Dated: March 26, 2021)

We report a proof-of-concept demonstration of a quantum order-finding algorithm for factoring the integer 21. Our demonstration involves the use of a compiled version of the quantum phase estimation routine, and builds upon a previous demonstration by Martín-López et al. in Nature Photonics 6, 773 (2012). We go beyond this work by using a configuration of approximate Toffoli gates with residual phase shifts, which preserves the functional correctness and allows us to achieve a complete factoring of $N = 21$. We implemented the algorithm on IBM quantum processors using only 5 qubits and successfully verified the presence of entanglement between the control and work register qubits, which is a necessary condition for the algorithm's speedup in general. The techniques we employ may be useful in carrying out Shor's algorithm for larger integers, or other algorithms in systems with a limited number of noisy qubits.

The main challenge

Model :

Unitary quantum computer



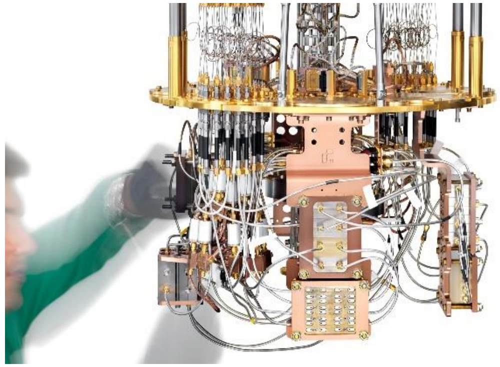
f.e. Shor algorithm (breaks RSA), quantum machine learning

quantum error correction

open quantum systems

Reality :

Noisy superconducting circuits



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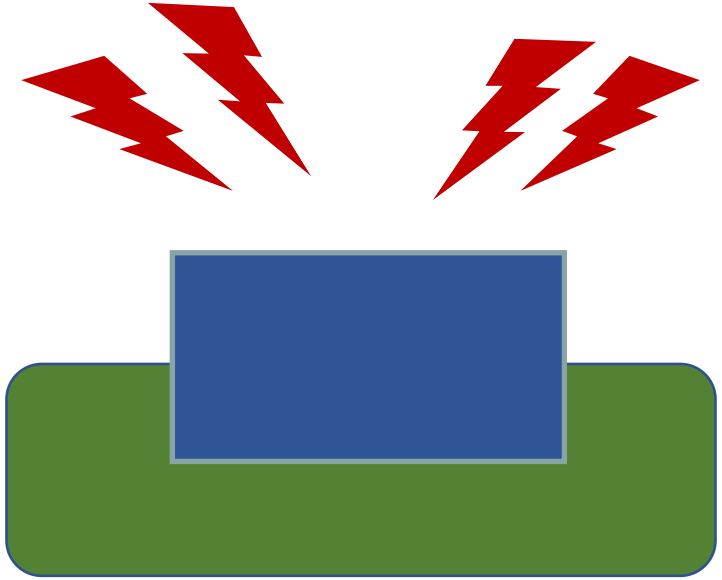
Quantum simulations with quantum computers on the cloud

Time dependent drive

Quantum system

Dissipative bath



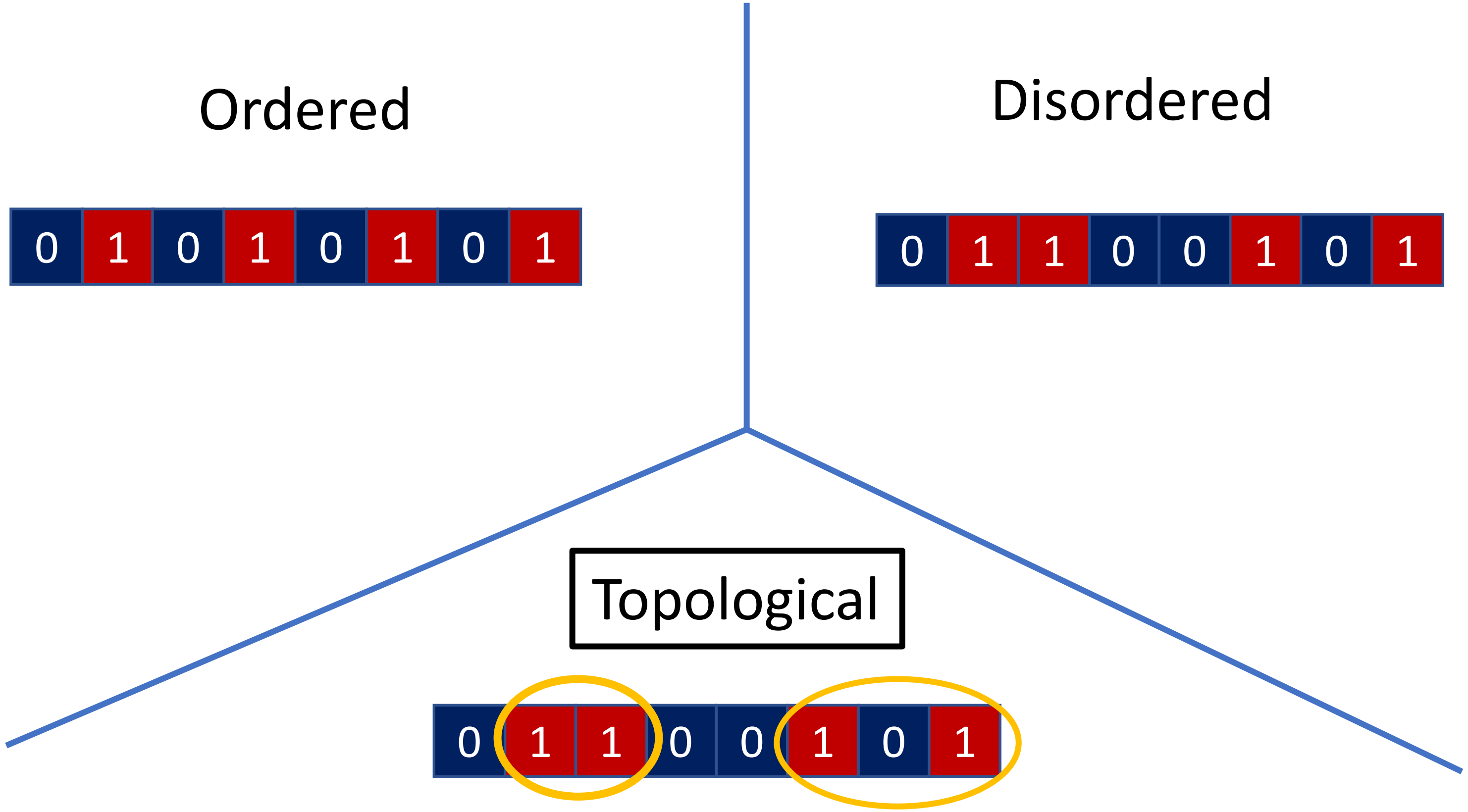
1. Periodic drives

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

2. Topological phases

Daniel Azses (BIU), Yehuda Naveh (IBM),
R. Haenel & R. Raussendorf (Montreal),
arXiv:2002.04620 (PRL, 2020)
arXiv:2008.09332 (PRB, 2020)

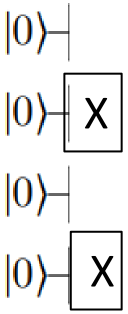
Quantum phases of matter



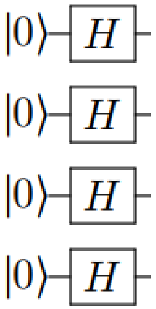

Haldane (1982), AKLT (1987), den Nijs&Rommelse (1989), Dalla Torre,Berg&Altman (2006), ….

Quantum phases of matter

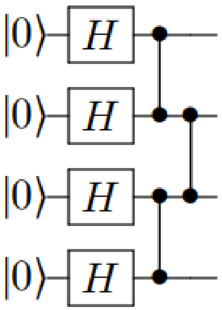
Ordered: Ising coupling



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

Symmetry resolved

reduced density matrix:

Trivial

$$\rho_A = \begin{pmatrix} \tilde{\rho}_A(+) & 0 \\ 0 & \tilde{\rho}_A(-) \end{pmatrix}$$

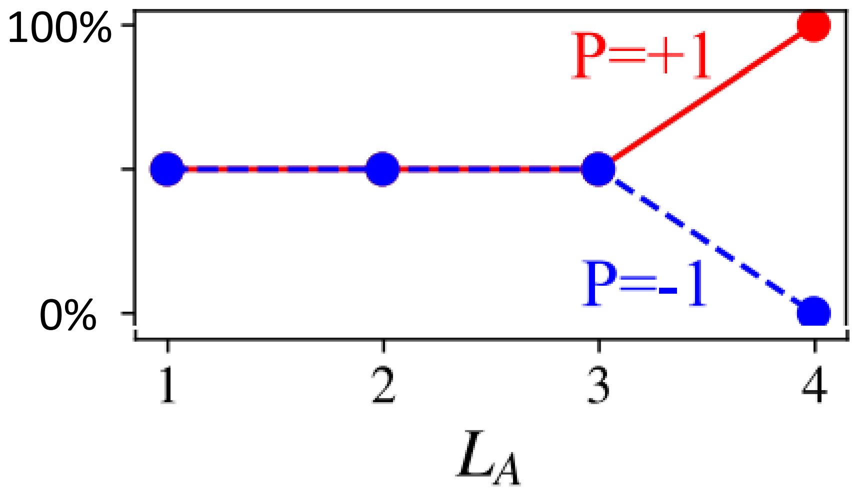
SPT

$$\rho_A = \begin{pmatrix} \tilde{\rho}_A(+) & 0 \\ 0 & \tilde{\rho}_A(-) \end{pmatrix}$$

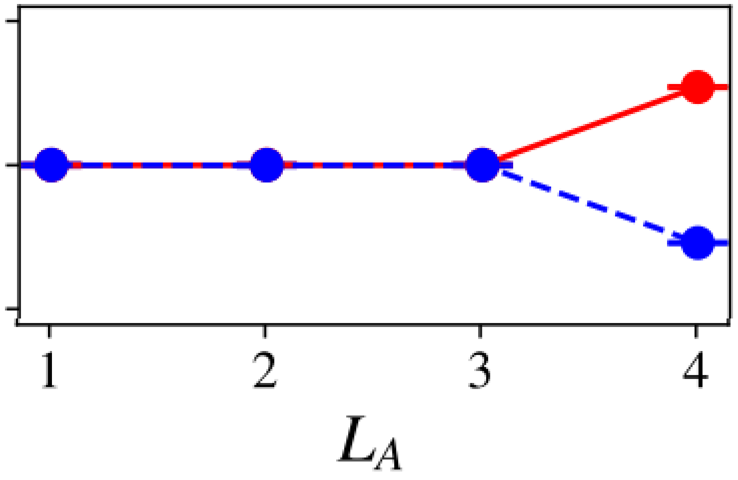
Goldstein & Sela (PRL, 2018)

Identifying a topological phases

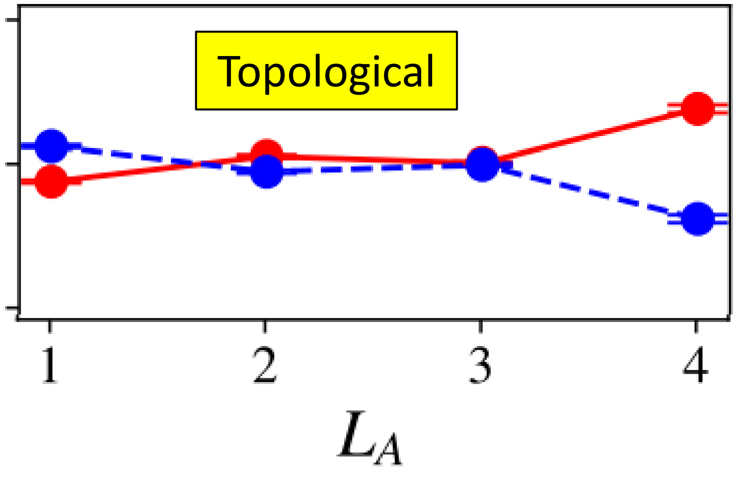
Unitary model

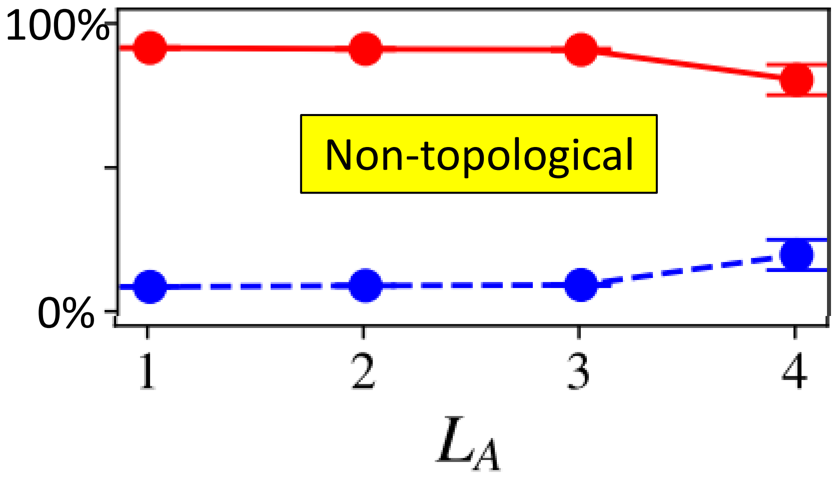


Noisy simulation
(QISKIT)



Experiment





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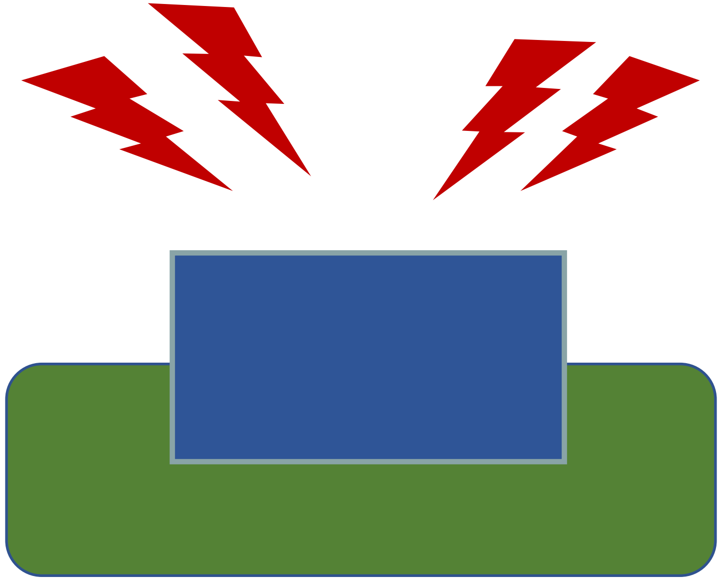

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3. Error mitigation

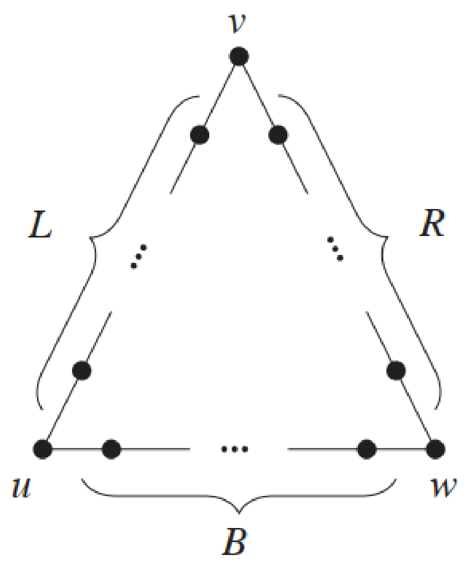
Meron Shefer (BIU), Daniel Azses (TAU)
IBM, Microsoft, Amazon (in preparation)

Main challenge:

Quantum advantage with shallow circuits

Solution:

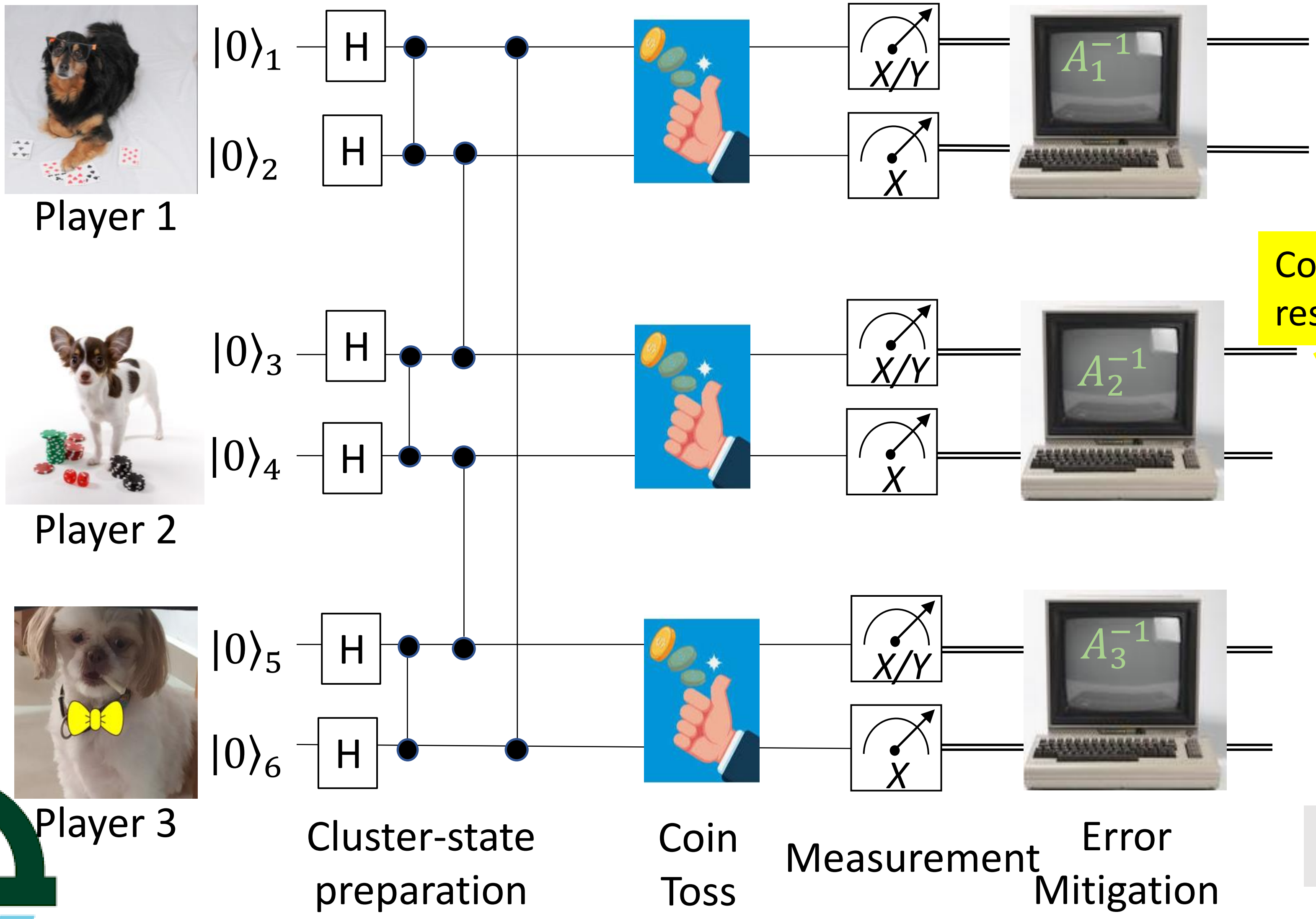
Non-local game using the cluster state on a triangle

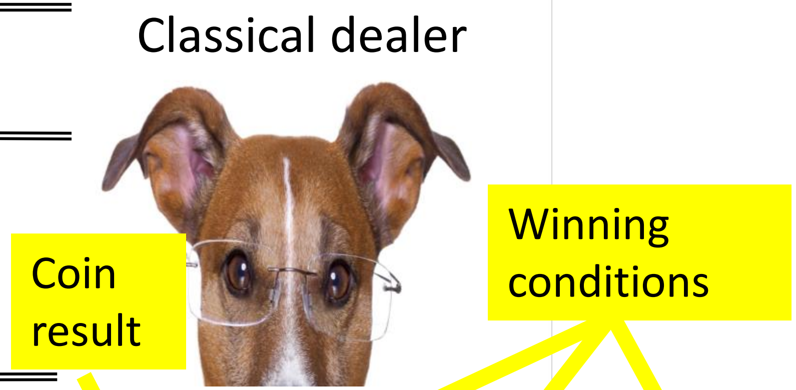


Bravyi, Gosset & Konig, Science 2018

Daniel & Myiaka, PRL 2021

Minimal realization : 3 players = 6 qubits

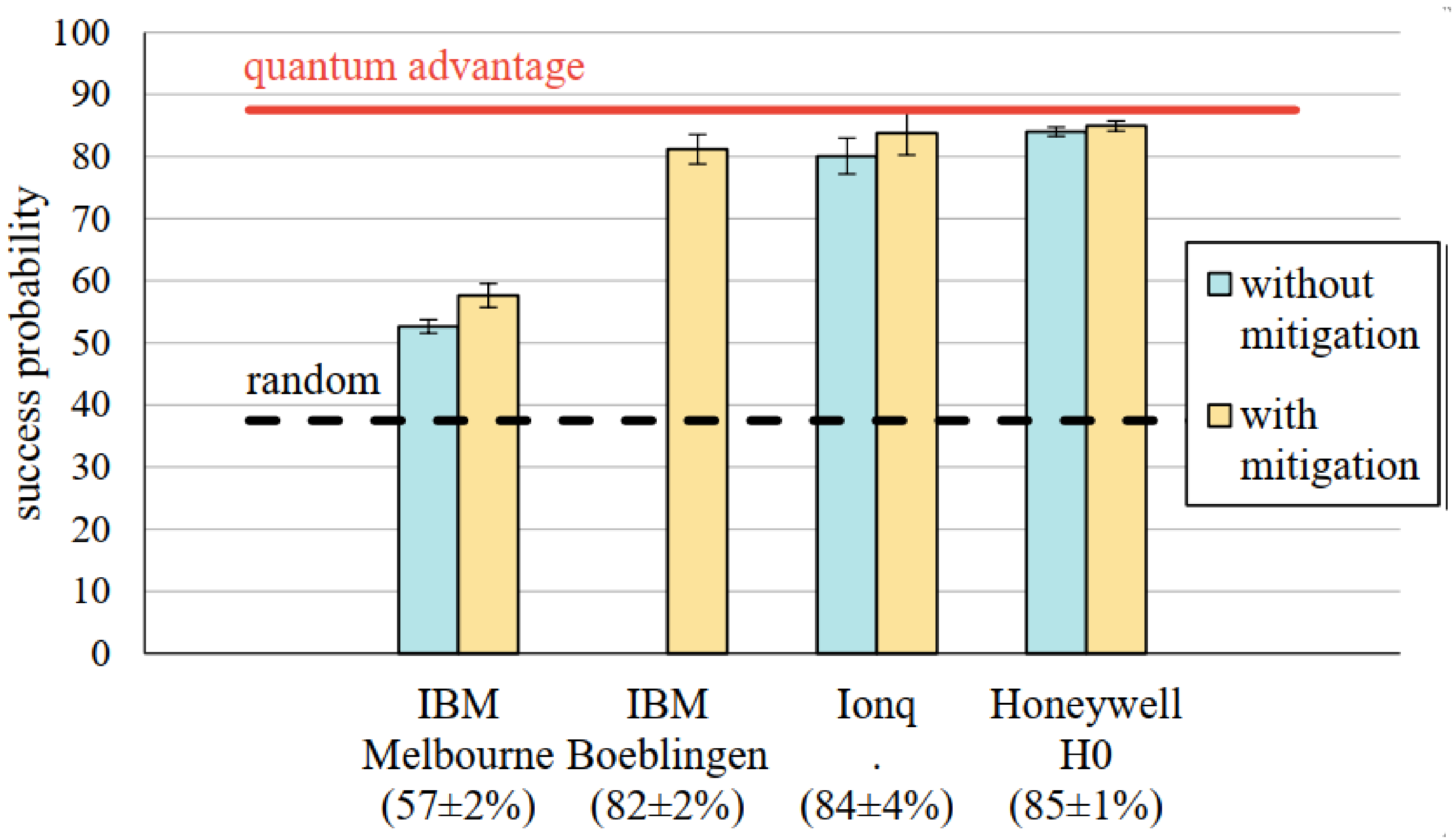




	aaa	bbb	dca
000	$X_1X_3X_5 = 1$	$X_2X_4X_6 = 1$	
001		$X_2X_4X_6 = 1$	
010		$X_2X_4X_6 = 1$	
011		$X_2X_4X_6 = 1$	$X_1Y_3X_4Y_5 = -1$
100		$X_2X_4X_6 = 1$	
101		$X_2X_4X_6 = 1$	$Y_1X_3Y_5X_6 = -1$
110		$X_2X_4X_6 = 1$	$Y_1X_2Y_3X_5 = -1$
111		$X_2X_4X_6 = 1$	

$$\langle P(\text{win})\rangle_{\text{classical}} < 7/8$$

Triangle game : results



If all the students fail a test… lower the bar!

Stabilizers

$$s_i = X_{i-1} Z_i X_{i+1}$$

$$s_i |\psi_{\text{cluster}}\rangle = |\psi_{\text{cluster}}\rangle$$

Sum of all products

$$S_{\text{all}} = 1 + \sum_i s_i + \sum_{i,j} s_i s_j + \cdots$$

$$S_{\text{all}} |\psi_{\text{cluster}}\rangle = 2^n |\psi_{\text{cluster}}\rangle$$

$$(S_{\text{all}})_{\text{classic,n=6}} \leq 28$$

Guhne, Toth, Hyllus, Briegel PRL (2005)

Optimal sum

$$S_{\text{optimal}} = \sum_{i,j} s_i s_j + \sum_{i,j,k} s_i s_j s_k + \sum_{i,j,k,l} s_i s_j s_k s_{k+1}$$

$$\langle S_{\text{optimal}} \rangle_{\text{IonQ}} = 41 \pm 0.5$$

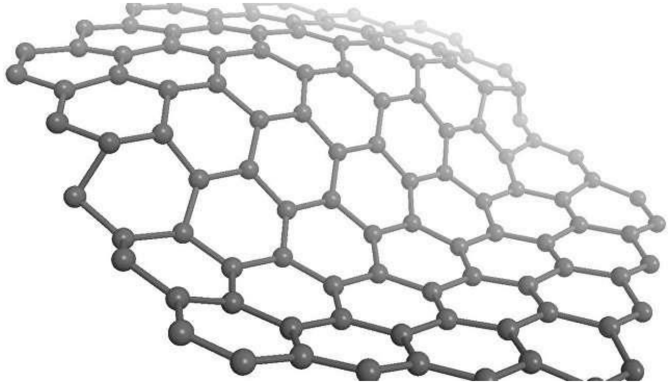
$$(S_{\text{optimal}})_{\text{classic,n=6}} \leq 19$$

Cabello, Guhne, Rodriguez PRA (2008)

Summary: Quantum simulations

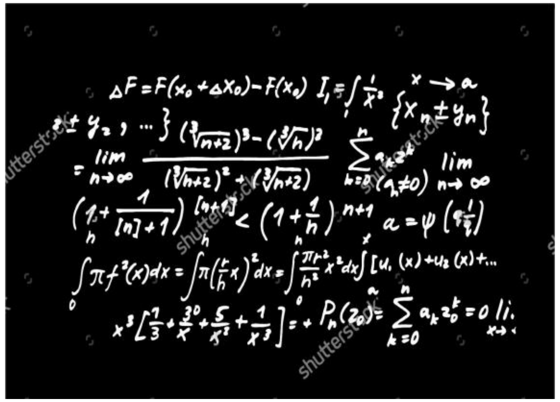
Quantum molecules/material

Size of Hilbert space = 2^{N_A}

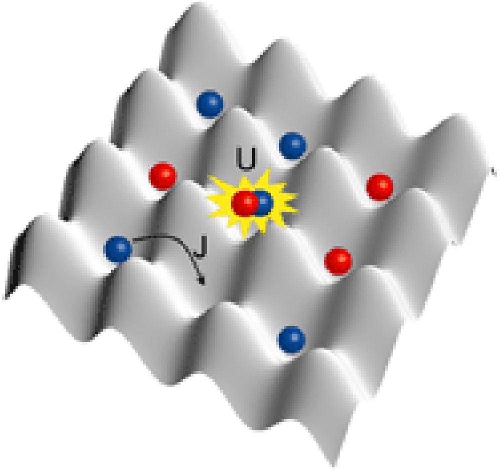


Classical supercomputers

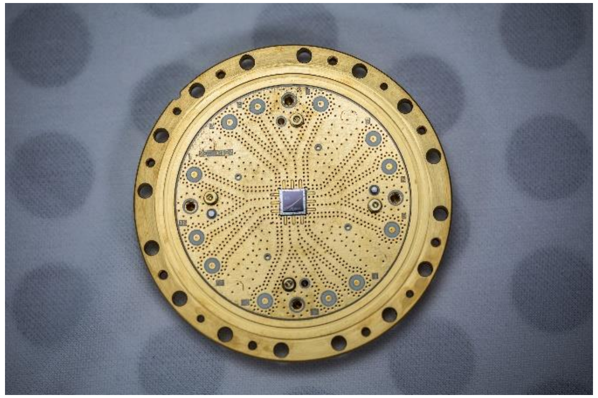
Quantum field theories

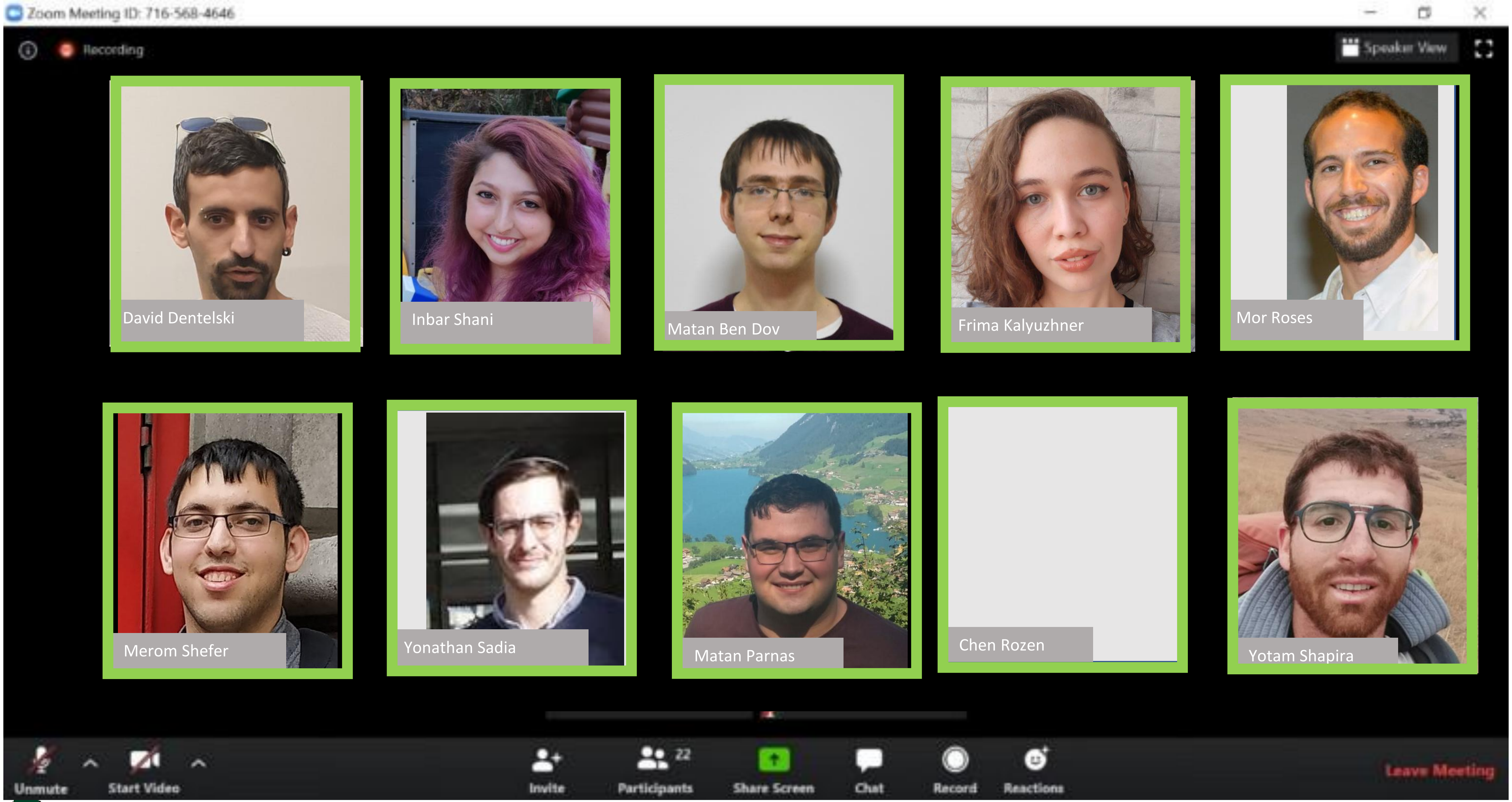


Ultracold atoms



Quantum computer on the cloud





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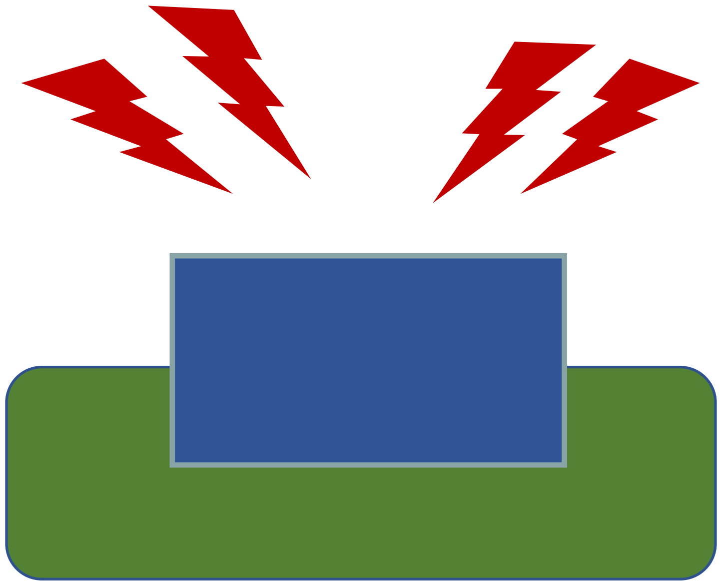

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