Exploring at the Intersection of Quantum Matter and Quantum Computing

Alexander (Lex) Kemper

Department of Physics
North Carolina State University
https://go.ncsu.edu/kemper-lab

Duke University Colloquium
11/12/2025

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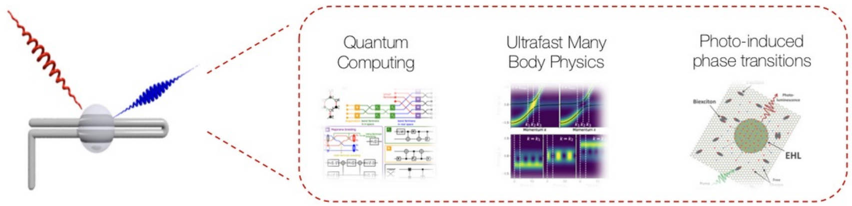


Kemper Lab

Quantum materials in and out of equilibrium.

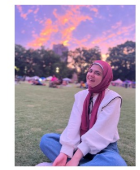
Collaborations with:

- Bojko Bakalov (NCSU Math)
- Marco Cerezo, Martin de la Rocca (LANL)
- Jim Freericks (Georgetown)
- Daan Camps, Roel van Beeumen, Bert de Jong, Akhil Francis (LBNL)
- Thomas Steckmann (UMD)
- Yan Wang, Eugene Dumitrescu (ORNL)
- Emanuel Gull (U. Michigan)
- Itay Hen (U. Southern California)

Current members


Alexander (Lex) Kemper
Principal investigator

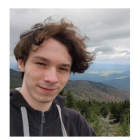

Anjali Agrawal
Graduate Researcher

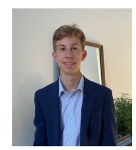

Heba Labib
Graduate Researcher


Norman Hogan
Graduate Researcher


Omar Alsheikh
Graduate Researcher

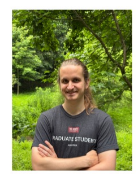

Goksu Toga
Postdoctoral Researcher


Liam Doak
Undergraduate Researcher


Aidan O'Bryan
Undergraduate Researcher

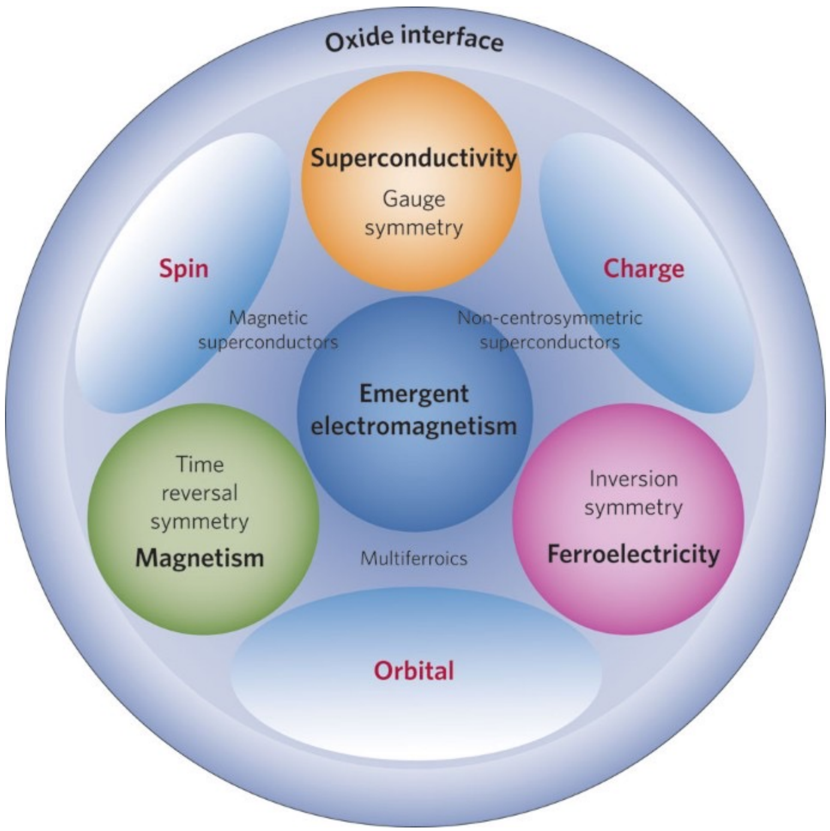

João C. Getelina
Postdoctoral Researcher


Muhammad Asaduzzaman (Asad)
Postdoctoral Researcher


Isaac Svedberg
Graduate Researcher


Raghav Jha
Postdoctoral Researcher

Quantum Information and Quantum Materials



H. Hwang, 10.1038/nmat3223

JoP D: Special Issue on Quantum Materials and Emerging Phenomena

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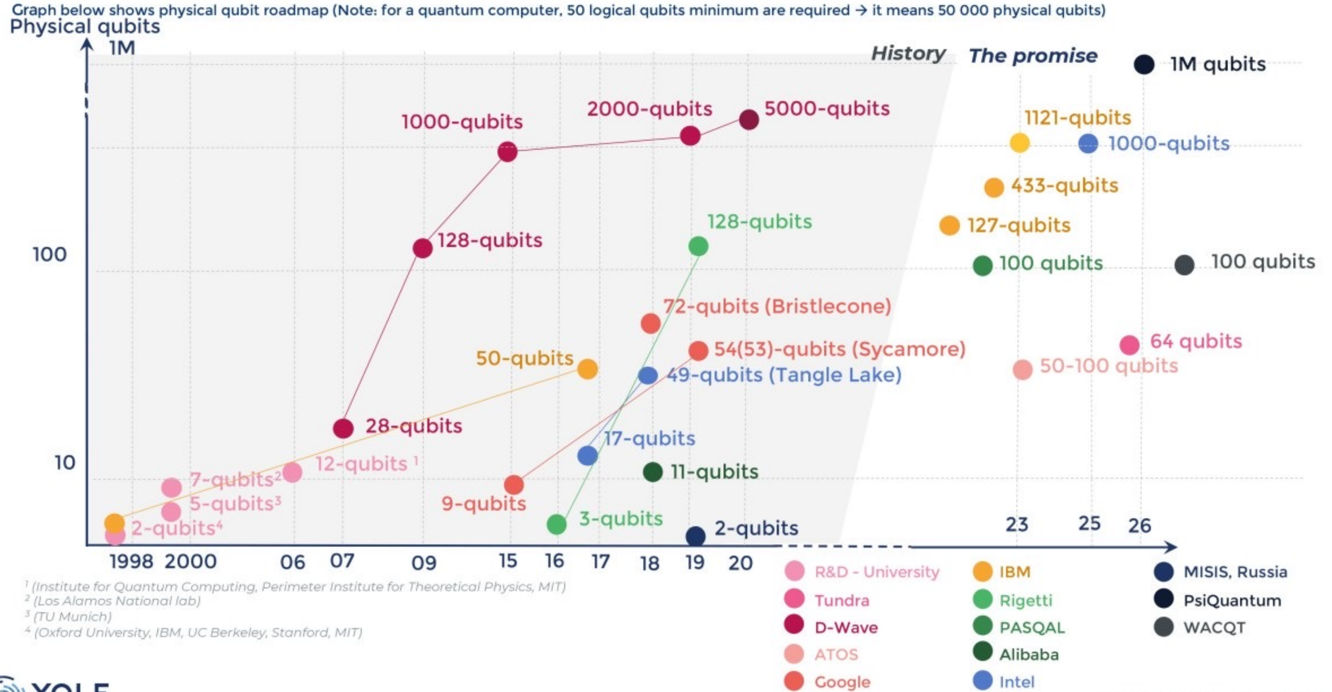
Brief outline

- Quantum Matter meets Quantum Computing
- Response functions
  - Why we care
  - How do find them
- A different paradigm: Making the experiment part of the simulation via linear response
- Beyond Quantum Simulation

PHYSICAL QUBIT ROADMAP FOR QUANTUM COMPUTER – HISTORY AND FUTURE

Source: Quantum Technologies report, Yole Développement, 2021

Graph below shows physical qubit roadmap (Note: for a quantum computer, 50 logical qubits minimum are required → it means 50 000 physical qubits)



[1] (Institute for Quantum Computing, Perimeter Institute for Theoretical Physics, MIT)
[2] (Los Alamos National lab)
[3] (TU Munich)
[4] (Oxford University, IBM, UC Berkeley, Stanford, MIT)

YOLE Intelligence

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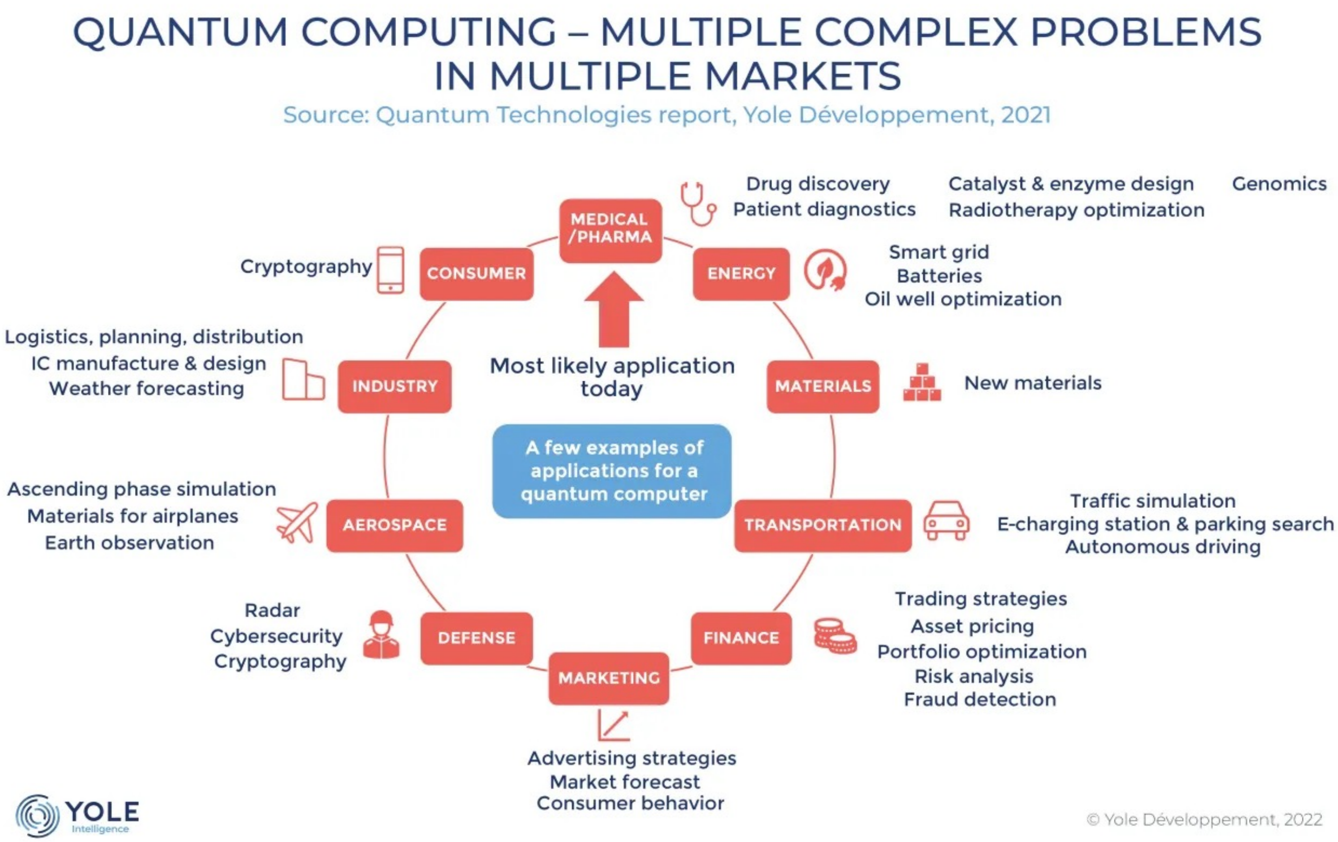
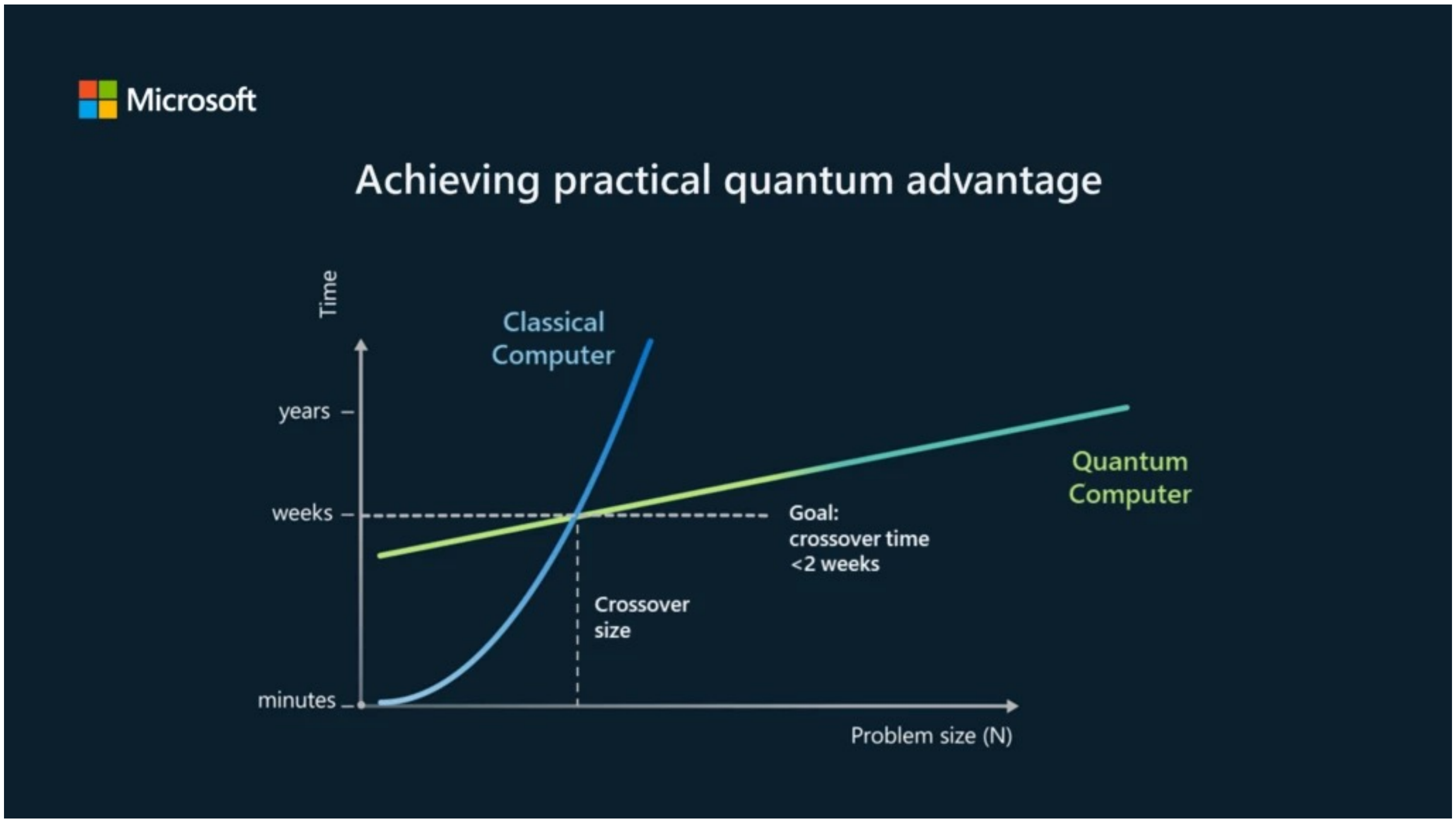
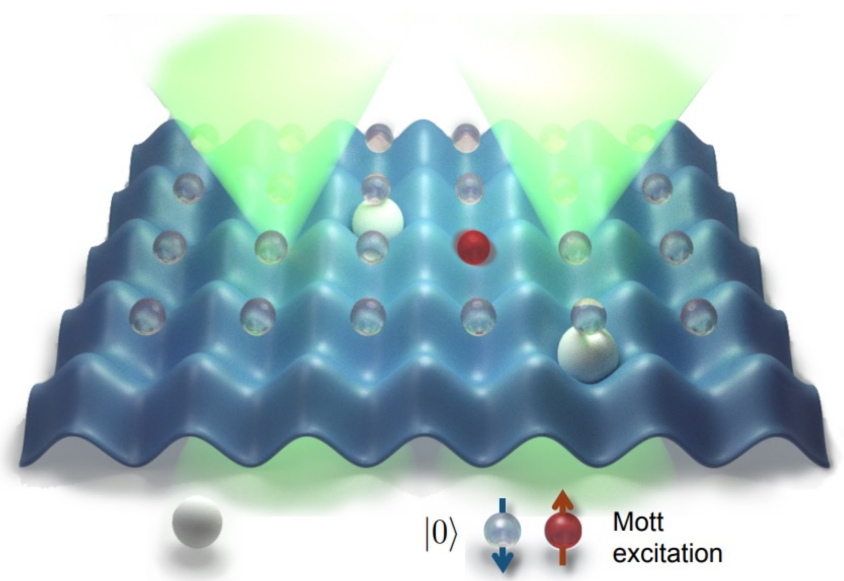
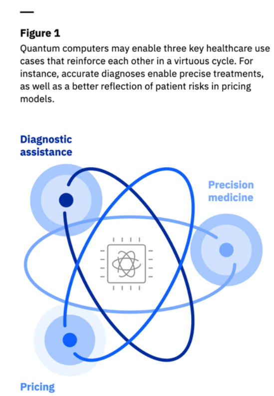
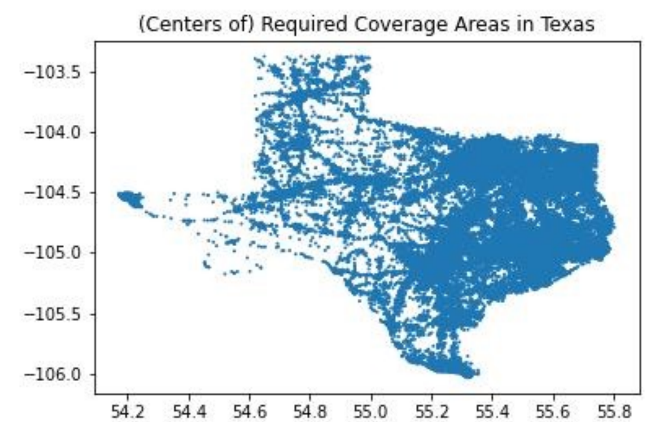



Microsoft
Achieving practical quantum advantage
Time
Classical Computer
years
weeks
minutes
Quantum Computer
Goal:
crossover time
<2 weeks
Crossover
size
Problem size (N)

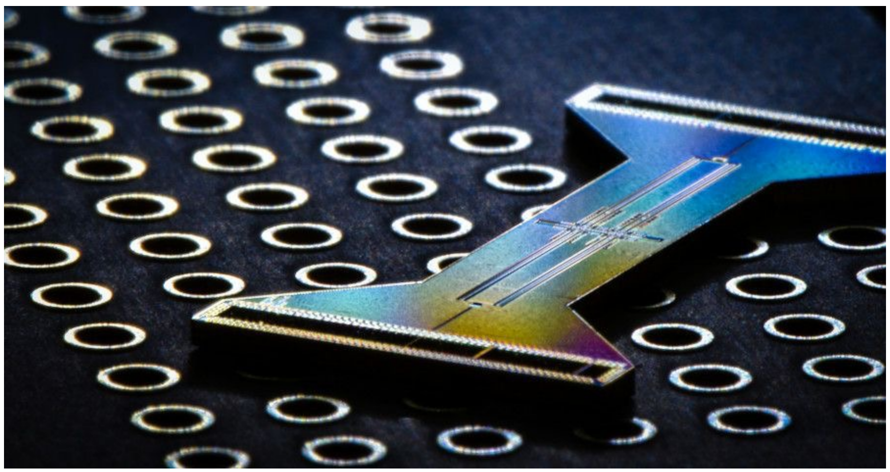
Bespoke quantum simulator *Digital algorithms*

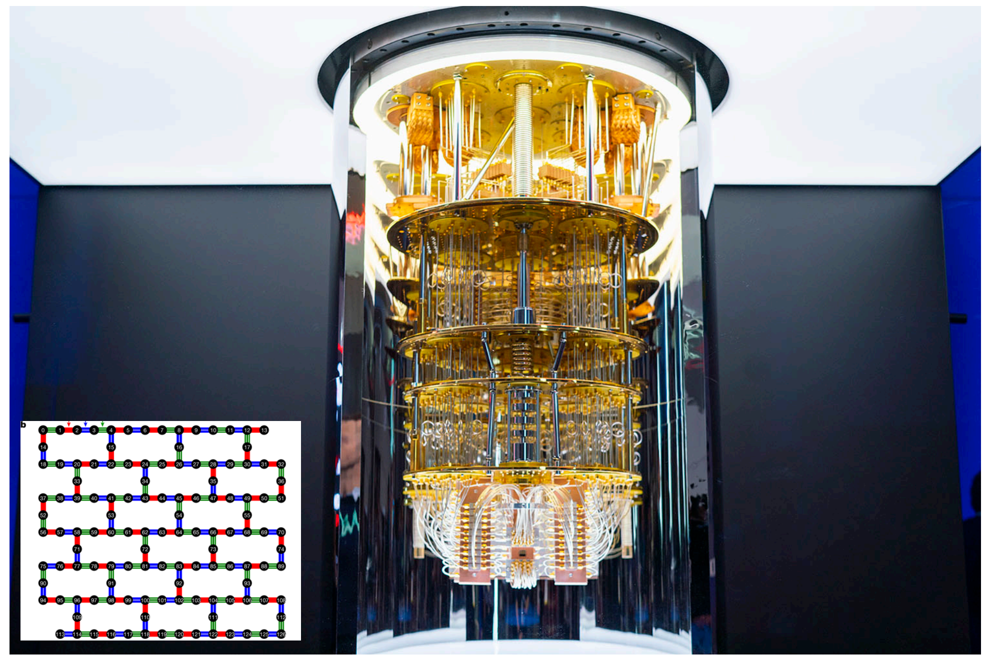






Bespoke quantum simulator — *Digital algorithms*





Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

Received May 7, 1981

1. Can classical physics be simulated by a classical computer?
2. Can quantum physics be simulated by a classical computer?
3. Can physics be simulated by a quantum computer?
4. Can a quantum simulation be universal?

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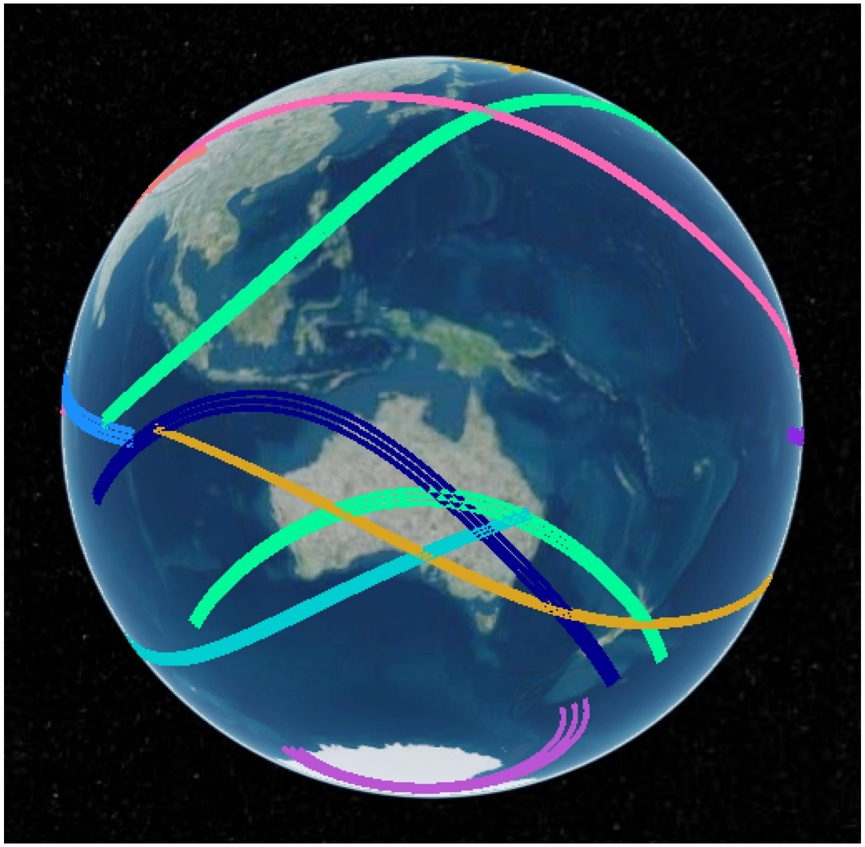

NASA

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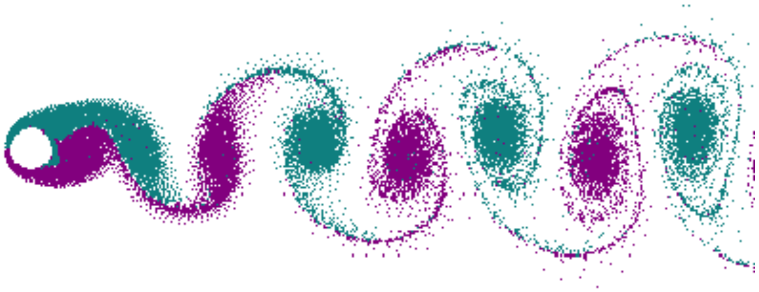

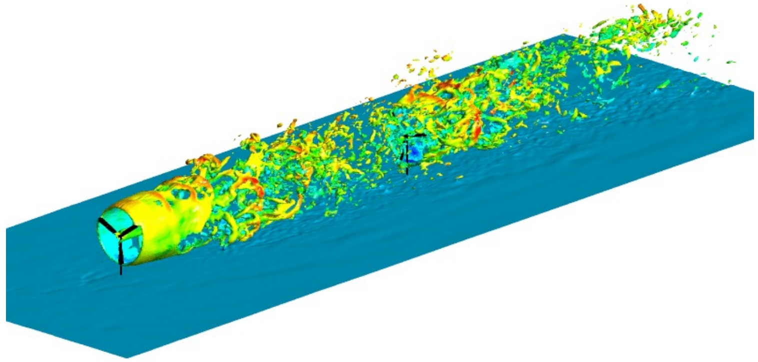

Wikipedia, https://fluids.eng.sydney.edu.au/computer-codes/

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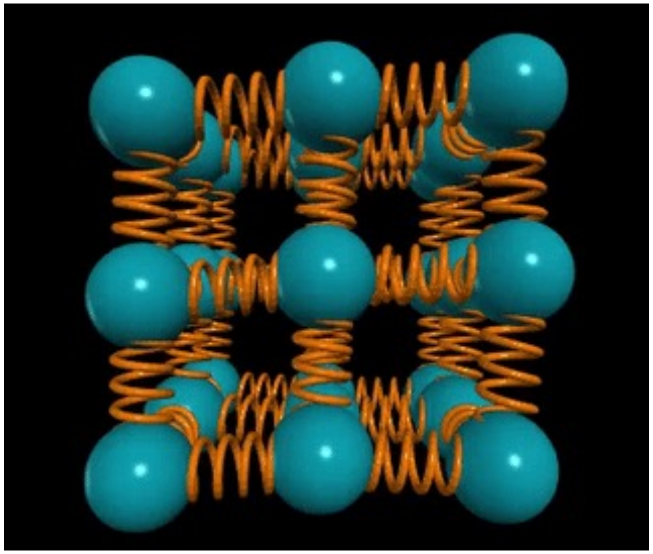

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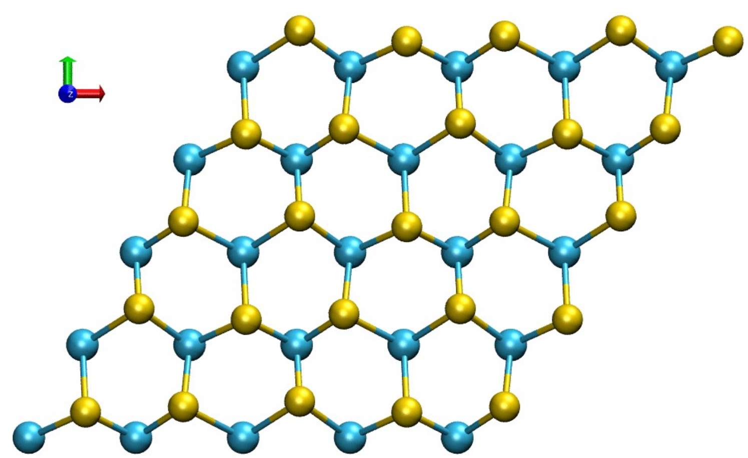
RESEARCH

TOPOLOGICAL MATTER

Observation of chiral phonons

Hanyu Zhu,[1,2] Jun Yi,[1] Ming-Yang Li,[3] Jun Xiao,[1] Lifa Zhang,[4] Chih-Wen Yang,[3] Robert A. Kaindl,[2] Lain-Jong Li,[3] Yuan Wang,[1,2*] Xiang Zhang[1,2*]

DOI: 10.1126/science.aar2711



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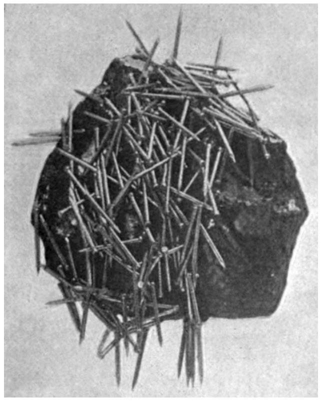
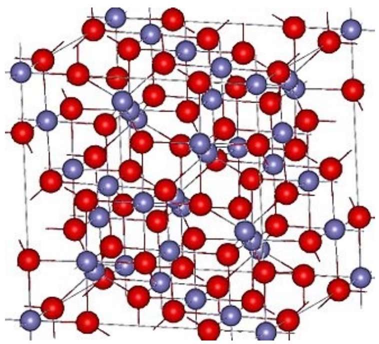
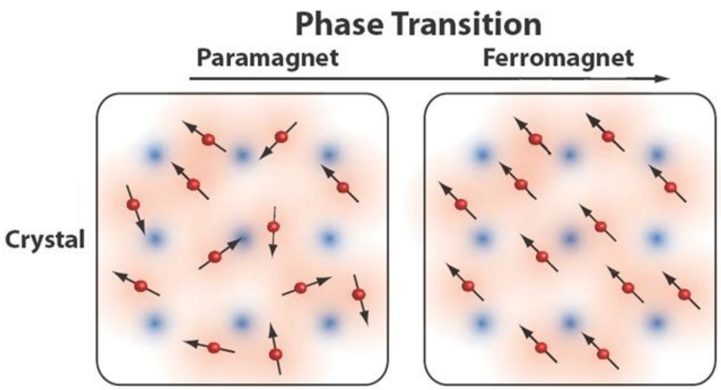
Magnetite $[Fe^{2+}(Fe^{3+})_2(O^{2-})_4]$





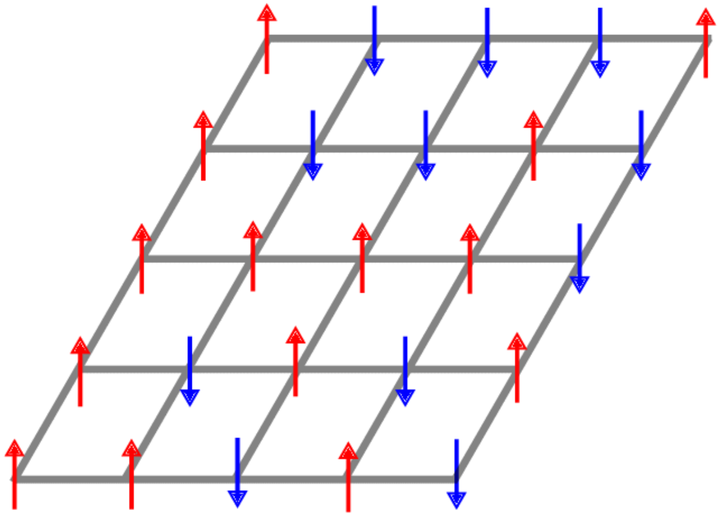



Published: February 1925

Beitrag zur Theorie des Ferromagnetismus

Ernst Ising

Zeitschrift für Physik **31**, 253–258 (1925) | Cite this article



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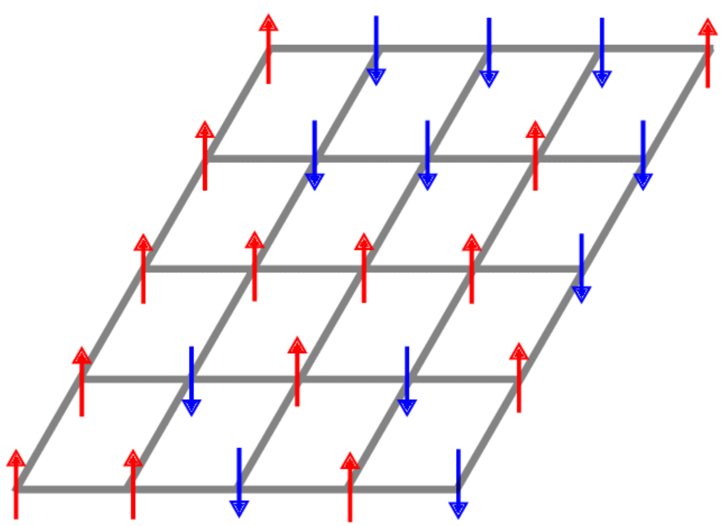

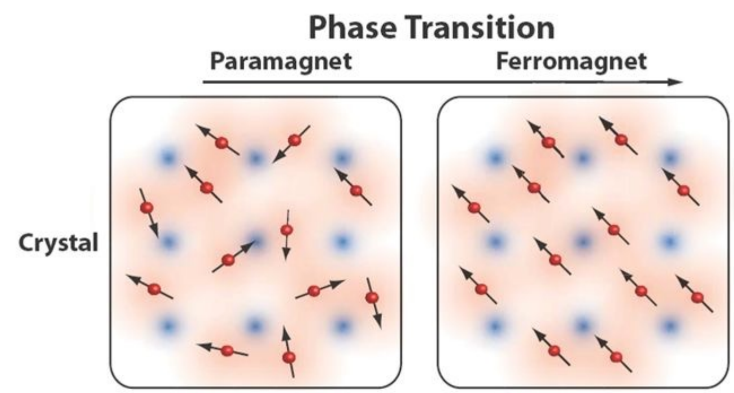

50 spins = ? states

a) 1,000 – 10,000
b) 10,000 – 1,000,000
c) 1,000,000 – 1,000,000,000
d) More than 1,000,000,000

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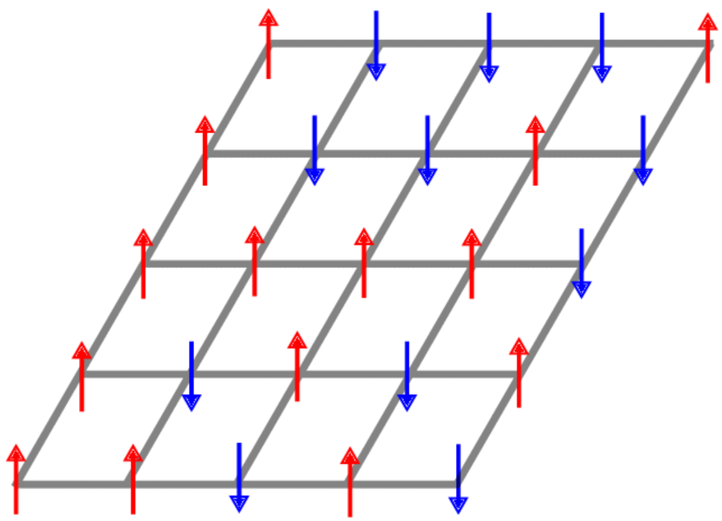
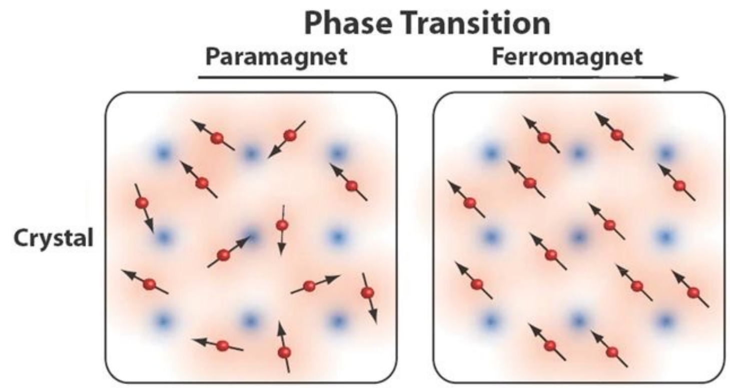
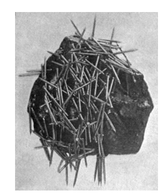




50 spins = 1,125,899,906,842,624 states

18 Petabytes of memory

10^{23} atoms



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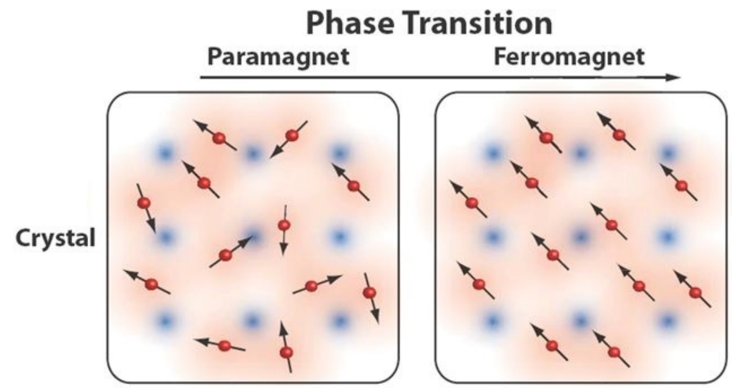

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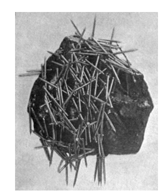

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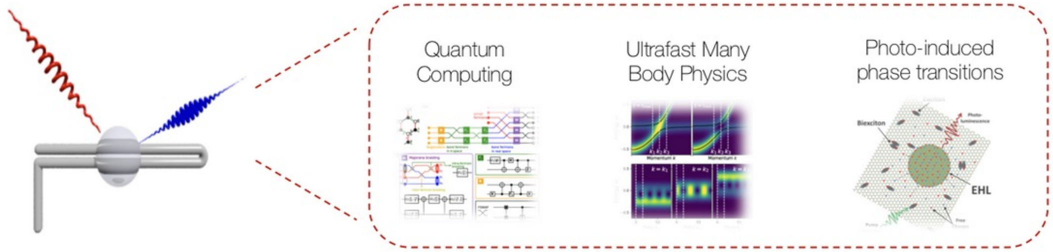

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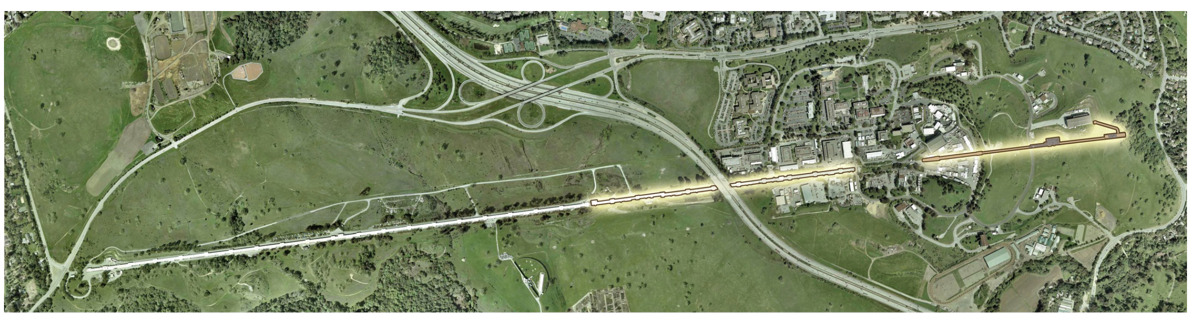
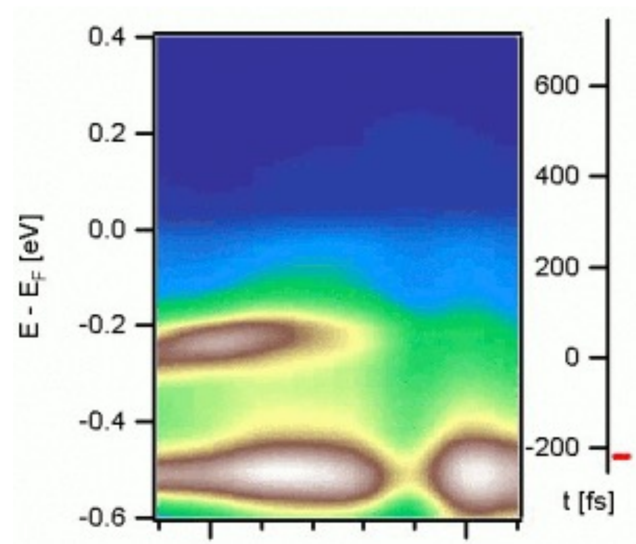
Quantum materials in and out of equilibrium.

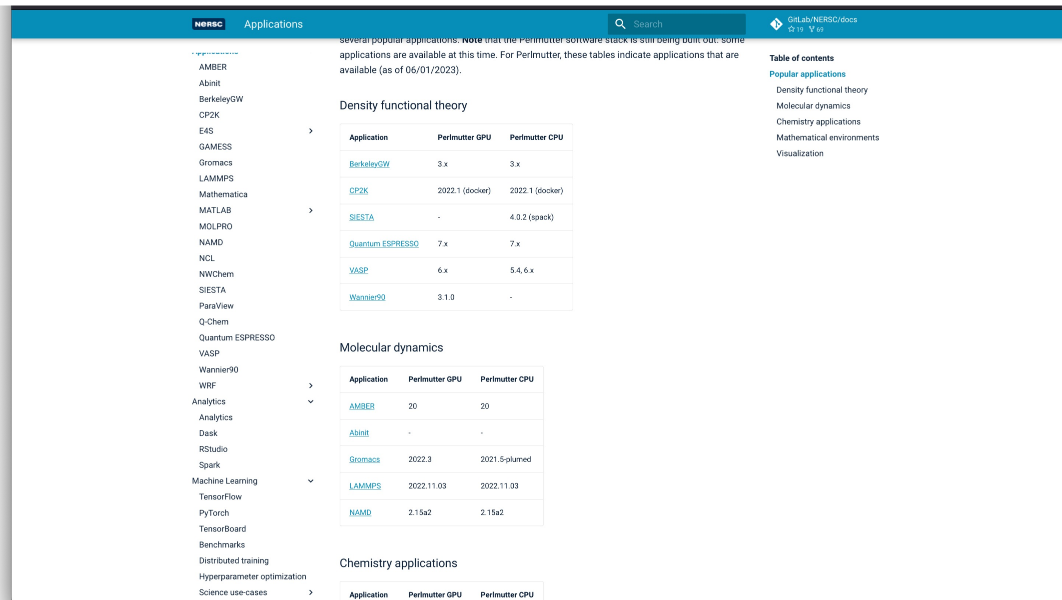
Time-resolved experiments





Shen group (Stanford)

2. Can quantum physics be simulated by a classical computer?



NERSC Applications

Search

GitLab/NERSC/docs

AMBER
Abinit
BerkeleyGW
CP2K
E4S
GAMESS
Gromacs
LAMMPS
Mathematica
MATLAB
MOLPRO
NAMD
NCL
NWChem
SIESTA
ParaView
Q-Chem
Quantum ESPRESSO
VASP
Wannier90
WRF
Analytics
Analytics
Dask
RStudio
Spark
Machine Learning
TensorFlow
PyTorch
TensorBoard
Benchmarks
Distributed training
Hyperparameter optimization
Science use-cases

applications are available at this time. For Perlmutter, these tables indicate applications that are available (as of 06/01/2023).

Density functional theory

Application	Perlmutter GPU	Perlmutter CPU
BerkeleyGW	3.x	3.x
CP2K	2022.1 (docker)	2022.1 (docker)
SIESTA	-	4.0.2 (spack)
Quantum ESPRESSO	7.x	7.x
VASP	6.x	5.4, 6.x
Wannier90	3.1.0	-

Molecular dynamics

Application	Perlmutter GPU	Perlmutter CPU
AMBER	20	20
Abinit	-	-
Gromacs	2022.3	2021.5-plumed
LAMMPS	2022.11.03	2022.11.03
NAMD	2.15a2	2.15a2

Chemistry applications

Application	Perlmutter GPU	Perlmutter CPU

Table of contents
Popular applications
Density functional theory
Molecular dynamics
Chemistry applications
Mathematical environments
Visualization

```
Density functional theory/GW
Exact diagonalization
Quantum Monte Carlo
Non-equilibrium Green's functions
Matrix Product States
Tensor Networks
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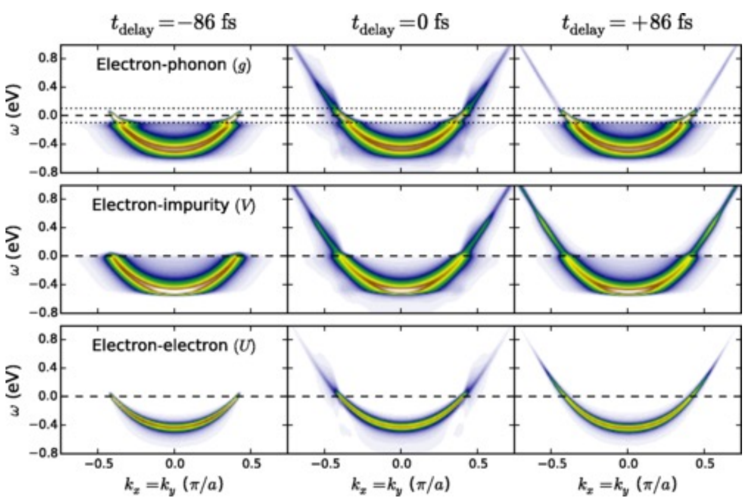
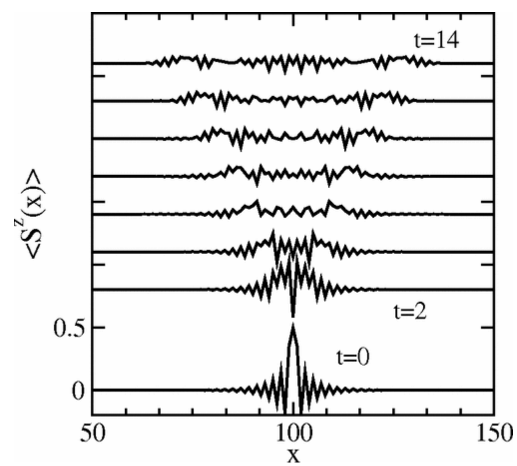
2. Can quantum physics be simulated by a classical computer?



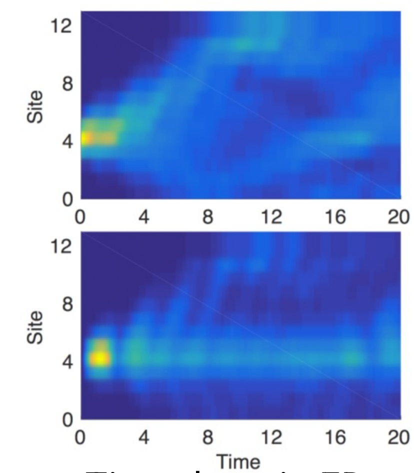
Non-Equilibrium Green's functions

Phys. Rev. X 8, 041009 (2018)



Time domain DMRG

Phys. Rev. Lett. 93, 076401 (2004)



Time domain ED

Johnston & Kemper, unpublished

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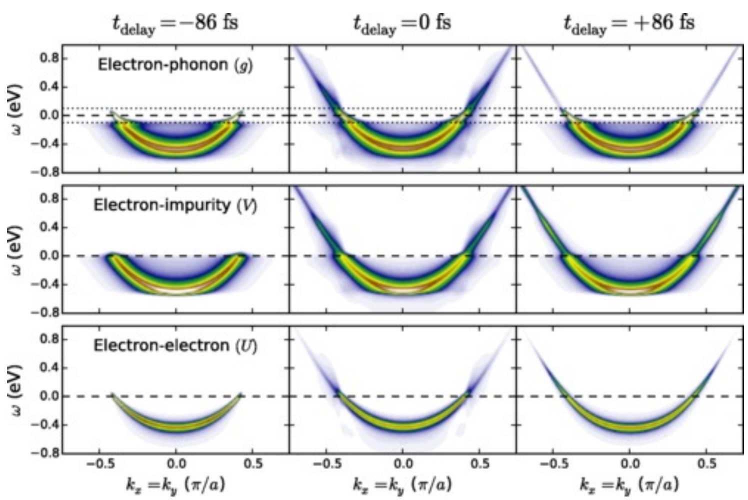
2. Can quantum physics be simulated by a classical computer?

All these techniques eventually reach a barrier.



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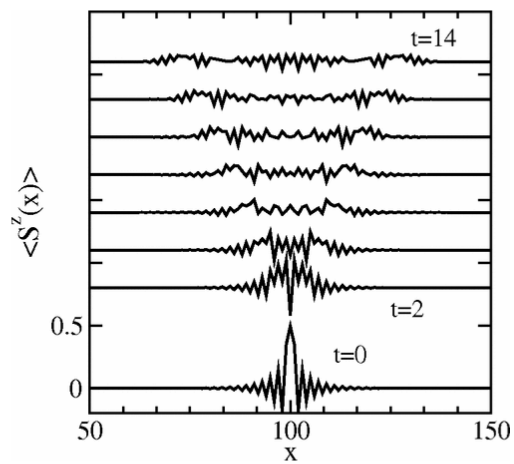
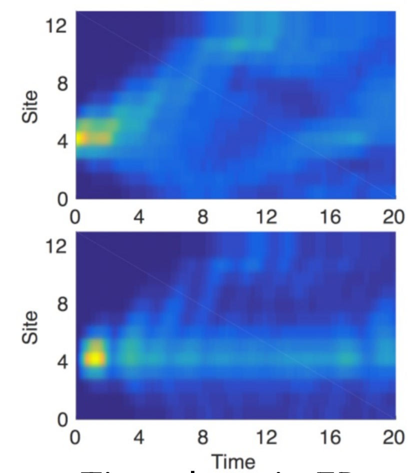


Time domain DMRG

Phys. Rev. Lett. 93, 076401 (2004)



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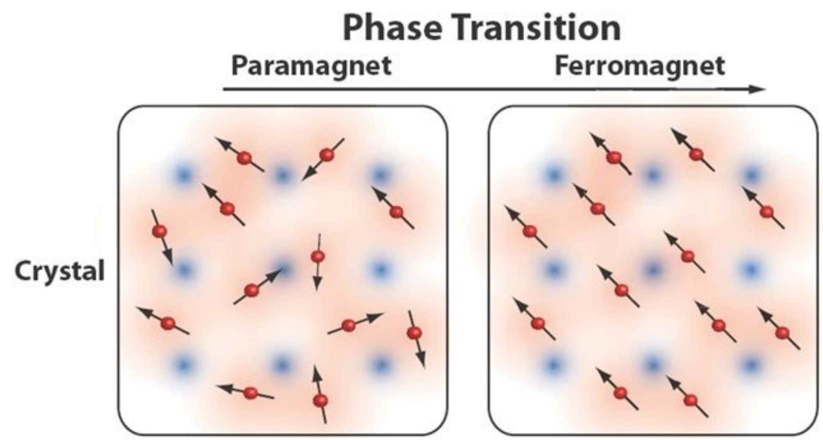

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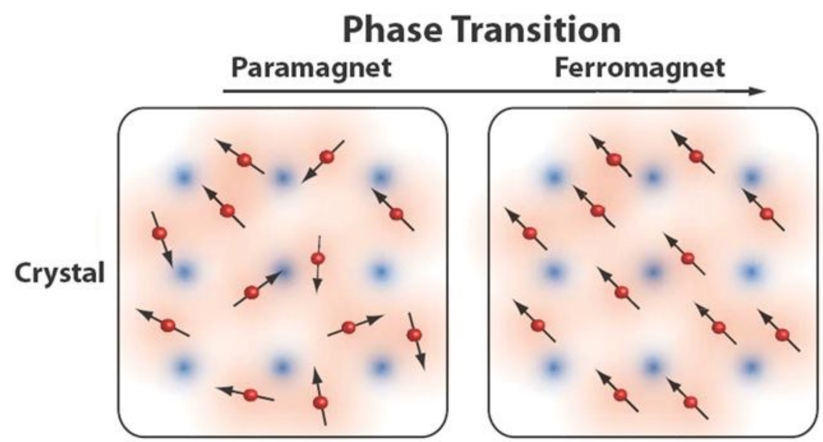


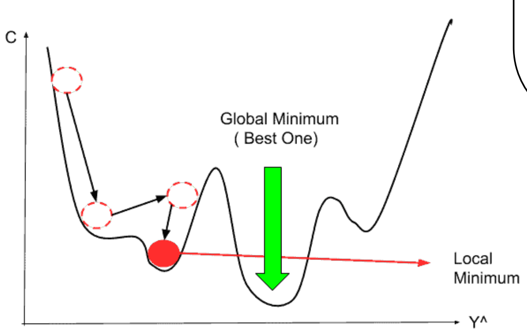
50 spins = 50 qubits

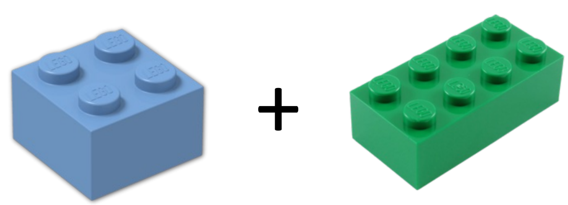
3. Can quantum physics be simulated by a quantum computer?

Variational Principle: $$E_{\text{ground}} \leq \langle \phi | \, H \, | \phi \rangle$$

Wave function guess:

$$\{\theta_i\} \longrightarrow \quad |\phi\rangle = e^{i\theta_1 \mathcal{O}_1} e^{i\theta_2 \mathcal{O}_2} \ldots e^{i\theta_n \mathcal{O}_n} |\phi_{\text{ref}}\rangle \quad \longrightarrow |\phi\rangle$$





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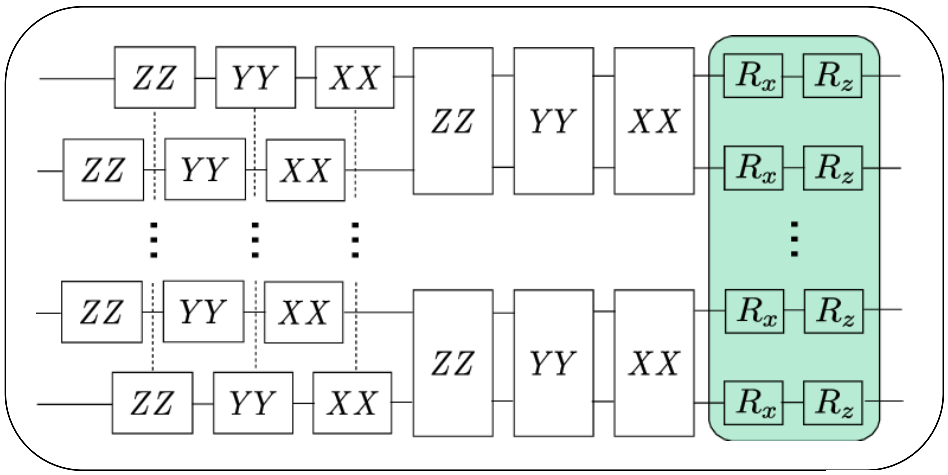
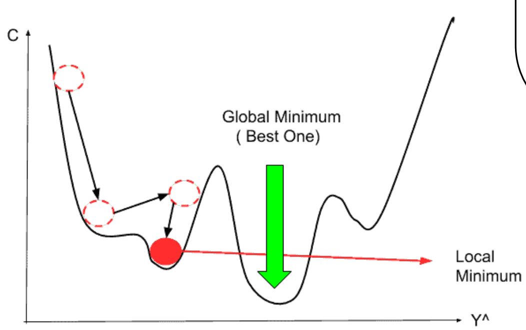
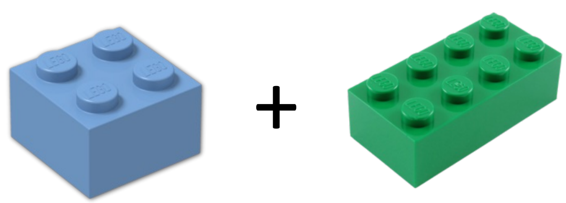


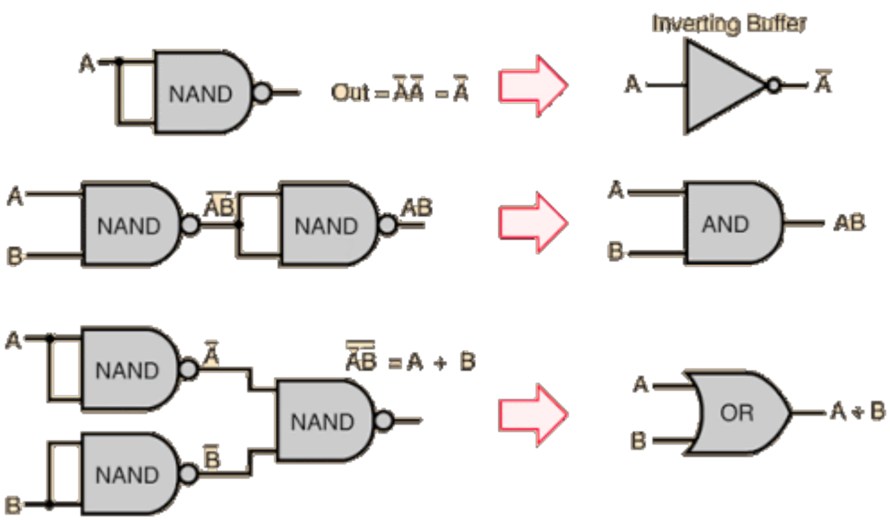
$\longrightarrow |\phi\rangle$



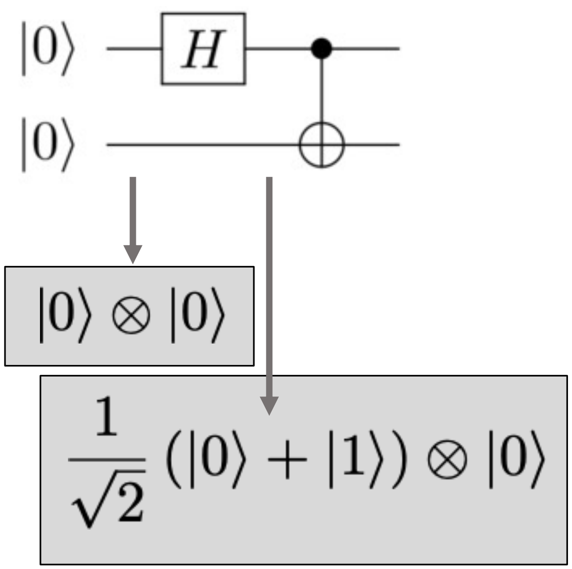


A very brief intro to quantum computing

Logical circuits



Quantum circuits



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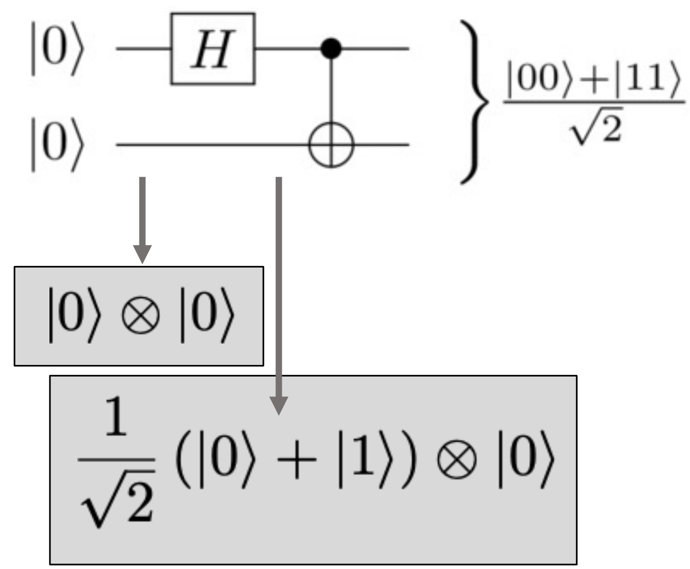
A very brief intro to quantum computing

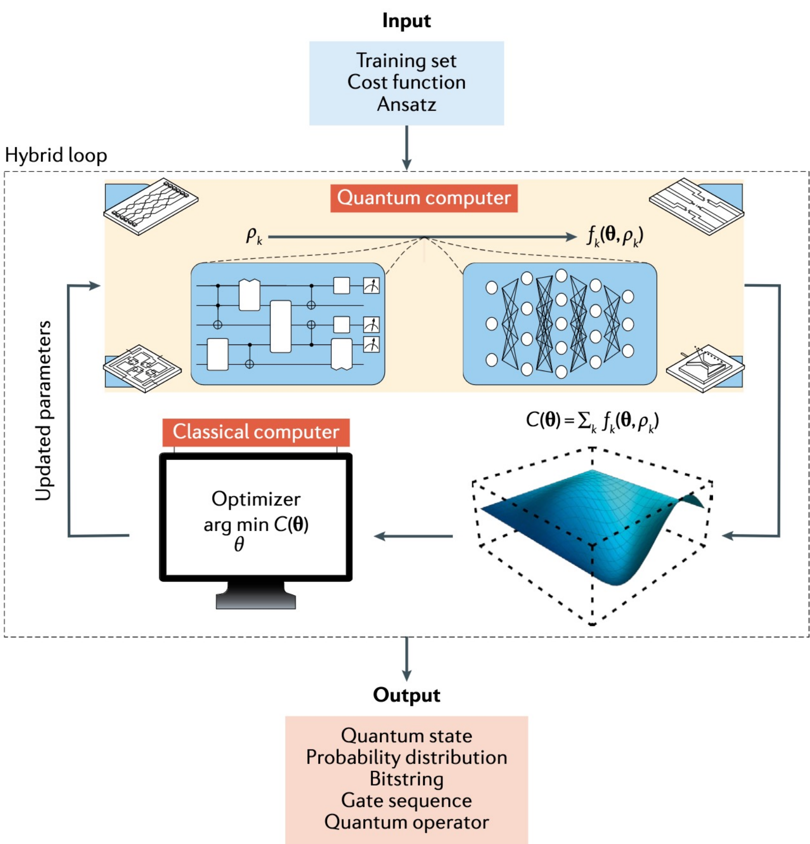
The Rules

1. You may only use unitary operations
2. More qubits = bad
3. More operations = bad
4. Complex qubit operations = bad
5. Your results will be very noisy anyway

Quantum circuits



3. Can quantum physics be simulated by a quantum computer?



Cost function: Energy of the molecular configuration

10.1038/nature23879

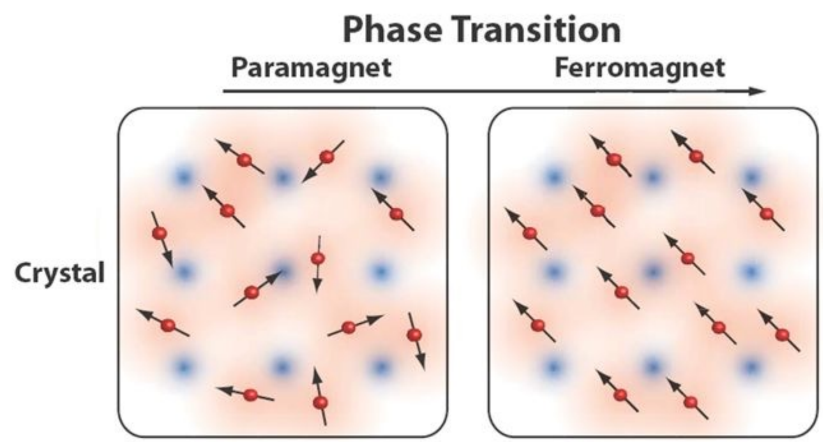
Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

Received May 7, 1981

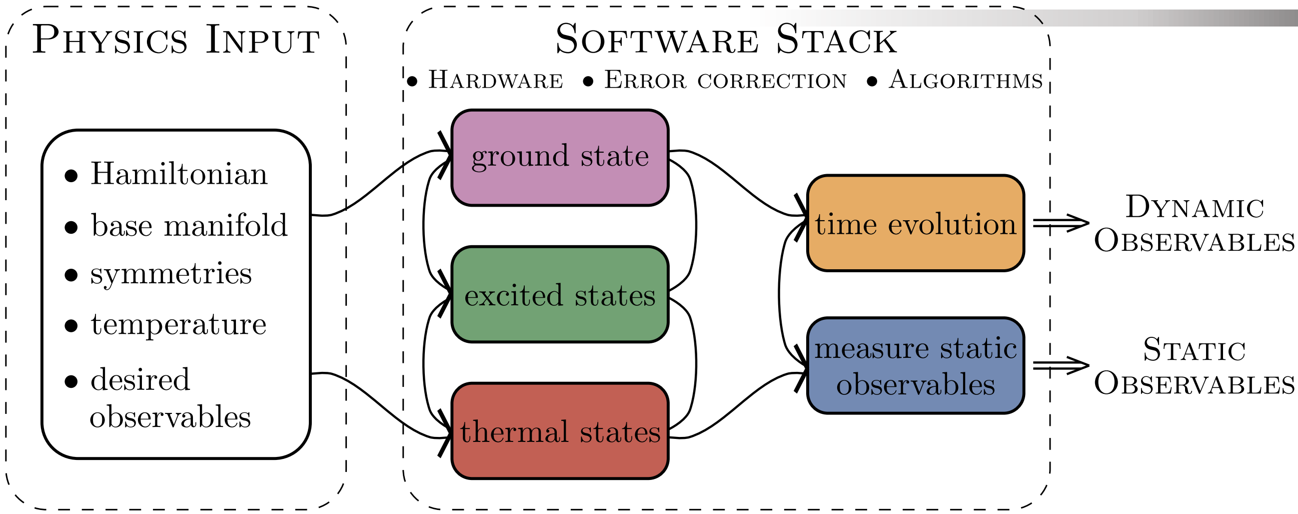
1. Can classical physics be simulated by a classical computer? ✓
2. Can quantum physics be simulated by a classical computer? ?
3. Can physics be simulated by a quantum computer? ✓



50 spins = 50 qubits

Quantum Information meets Quantum Matter

A-Z quantum simulation



Classical post-processing techniques

Prepare state of interest

- *Physics-Informed Subspace Expansions*
- *Barren optimization plateaus*

Time evolve

- *Lie-algebraic methods for time evolution*
- *Open quantum system evolution*

Dynamical response functions

- *Neutron scattering (magnon) spectra*
- *Open quantum system Green's functions*
- *Dynamical Mean Field Theory*

Q: What do you do with a quantum state once you've prepared one?

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Ising Model

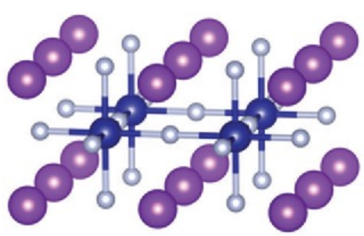
794 *Brazilian Journal of Physics, vol. 30, no. 4, December, 2000*

The Ising Model and Real Magnetic Materials

W. P. Wolf
Yale University, Department of Applied Physics,
P.O. Box 208284, New Haven, Connecticut 06520-8284, U.S.A.

Received on 3 August, 2000

The factors that make certain magnetic materials behave similarly to corresponding Ising models are reviewed. Examples of extensively studied materials include $Dy(C_2H_5SO_4)_3.9H_2$ (DyES), $Dy_3Al_5O_{12}$ (DyAlG), $DyPO_4$, $Dy_2Ti_2O_7$, $LiTbF_4$, K_2CoF_4, and Rb_2CoF_4. Various comparisons between theory and experiment for these materials are examined. The agreement is found to be generally very good, even when there are clear differences between the ideal Ising model and the real materials. In a number of experiments behavior has been observed that requires extensions of the usual Ising model. These include the effects of long range magnetic dipole interactions, competing interaction effects in field-induced phase transitions, induced staggered field effects and frustration effects, and dynamic effects. The results show that the Ising model and real magnetic materials have provided an unusually rich and productive field for the interaction between theory and experiment over the past 40 years.



10.1039/c6cp02362b

Heisenberg model

PHYSICAL REVIEW B
covering condensed matter and materials physics

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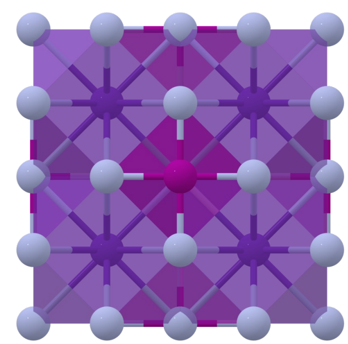
Critical behavior of the three-dimensional Heisenberg antiferromagnet $\mathbf{RbMnF_3}$

R. Coldea, R. A. Cowley, T. G. Perring, D. F. McMorrow, and B. Roessli
Phys. Rev. B **57**, 5281 – Published 1 March 1998

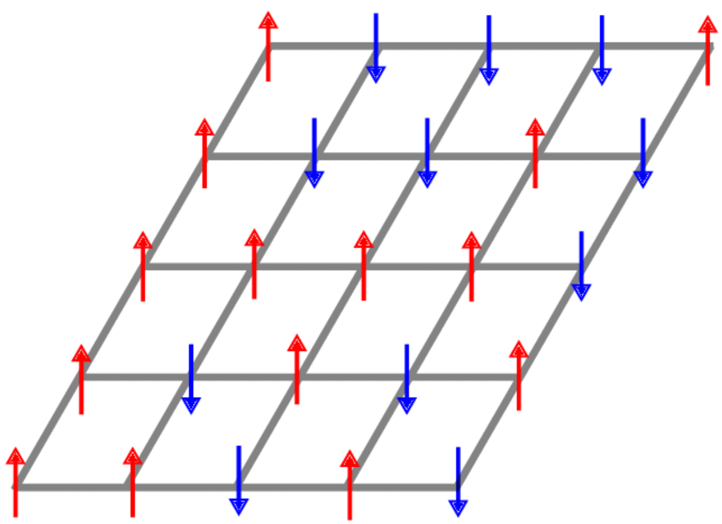


Materials project

NC STATE UNIVERSITY

Ising Model

$$\mathcal{H} = -J\sum_i \sigma_i^z \sigma_{i+1}^z + h_x \sum_i \sigma_i^x$$



Heisenberg model

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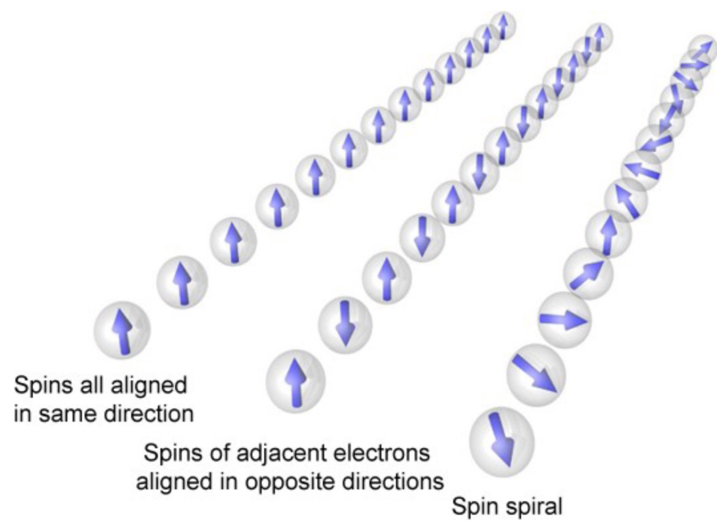

NC STATE UNIVERSITY

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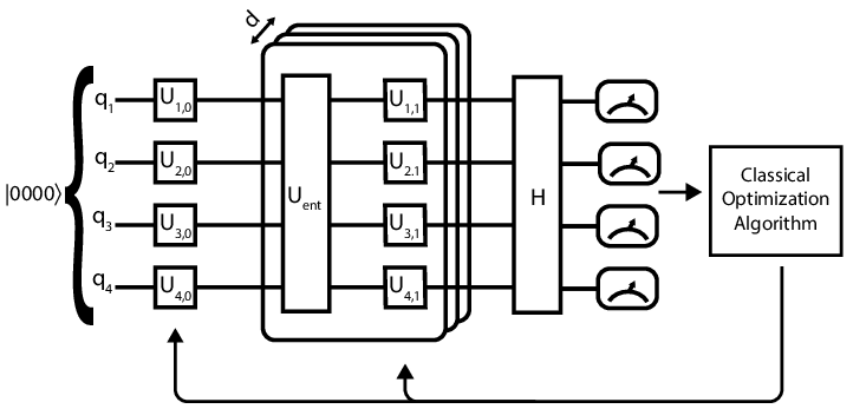

[Optimization of the Variational Quantum Eigensolver for Quantum Chemistry Applications]()

Heisenberg model

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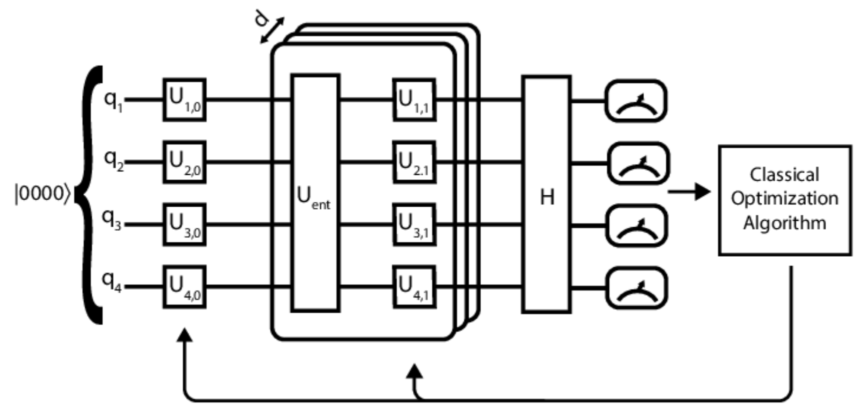

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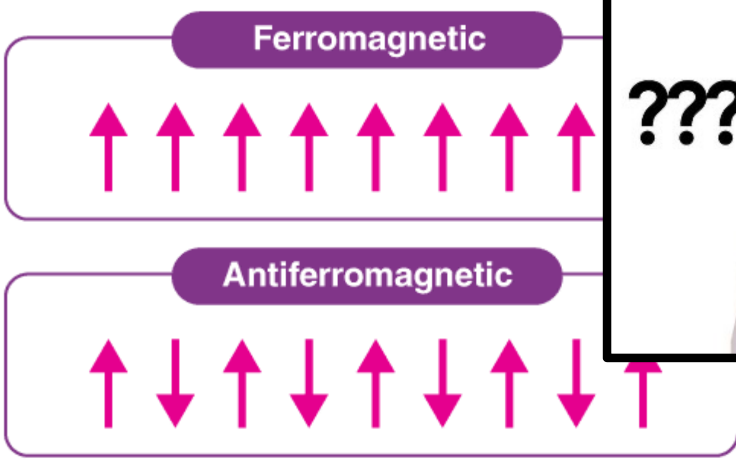

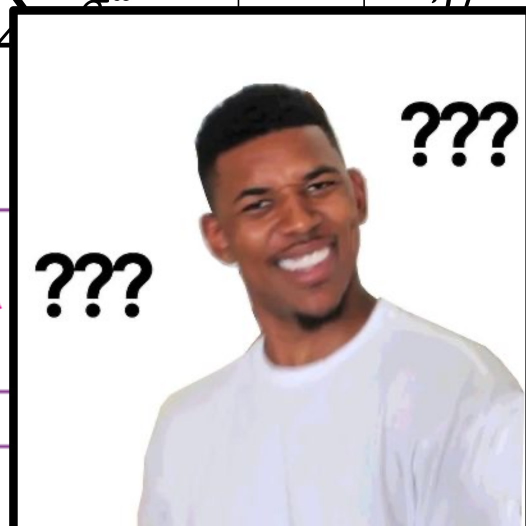

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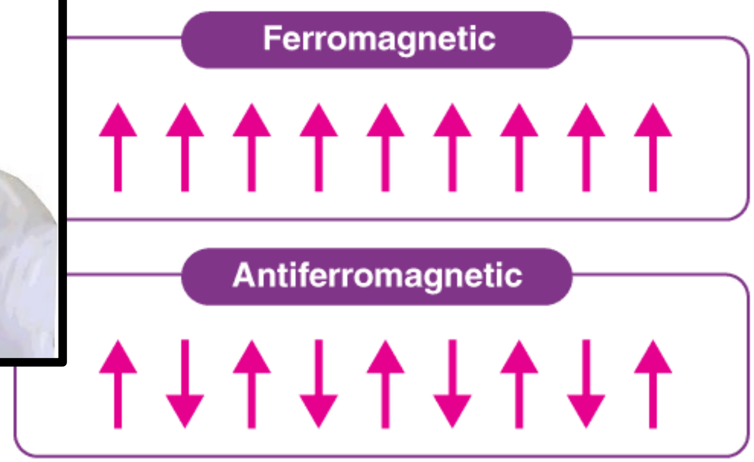
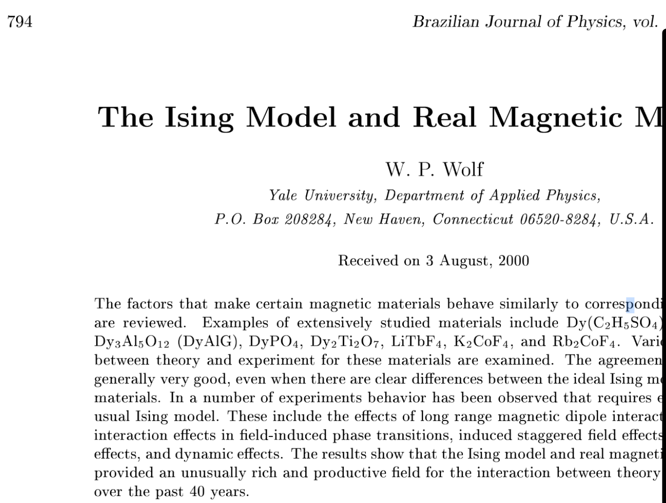


Ising Model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The Ising Model and Real Magnetic M

W. P. Wolf

Yale University, Department of Applied Physics,
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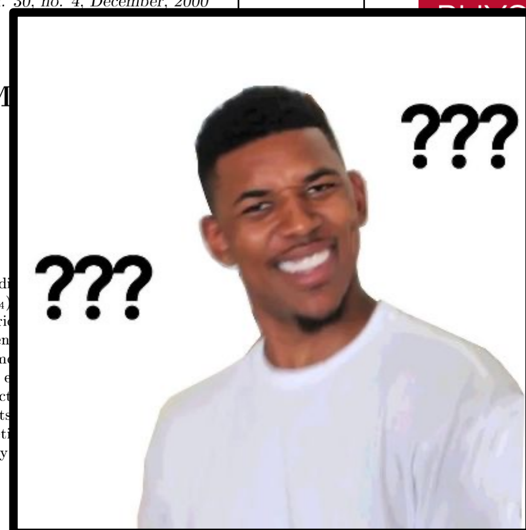
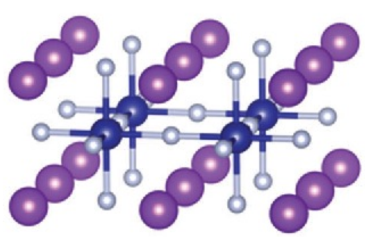
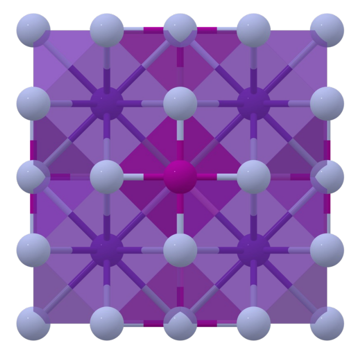




10.1039/c6cp02362b

Heisenberg model



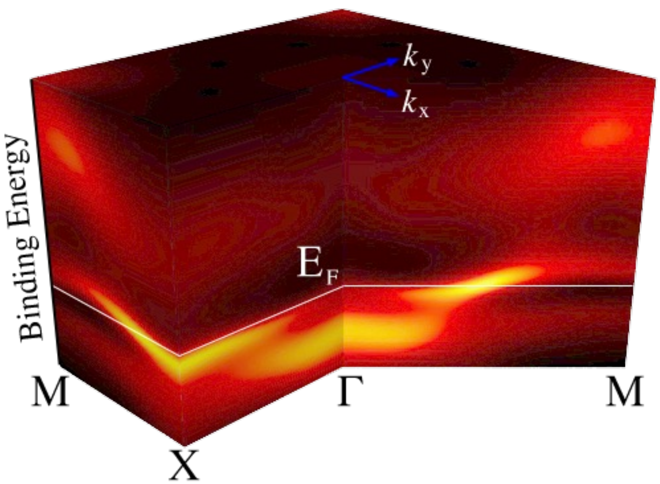
Materials project

Q: What do you do with a quantum state once you've prepared one?

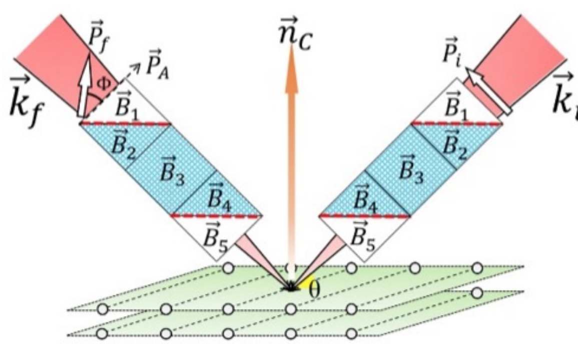
A: You measure its excitations.

Measuring Excitations

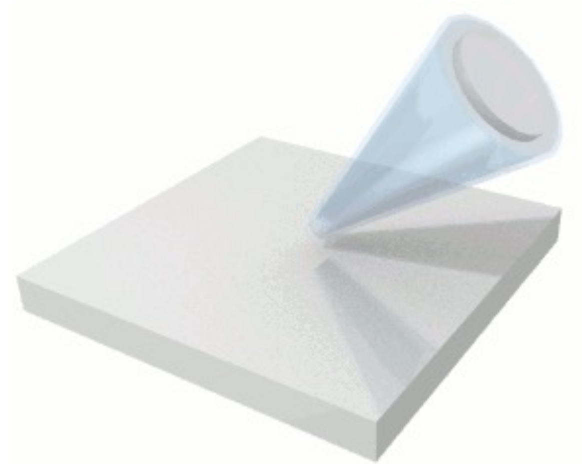
Figures courtesy of Devereaux/Shen group and ORNL



Angle-resolved Photoemission (ARPES)

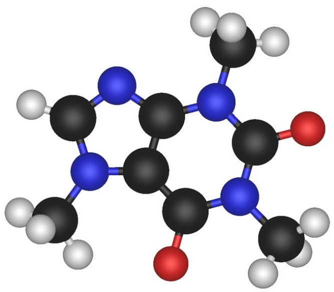


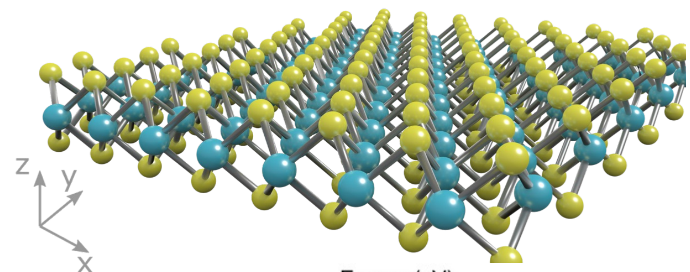
Neutron Scattering

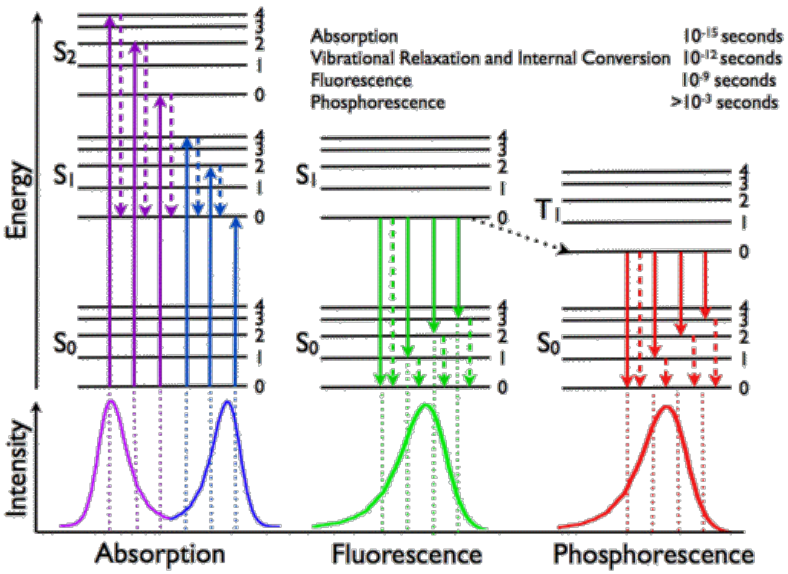


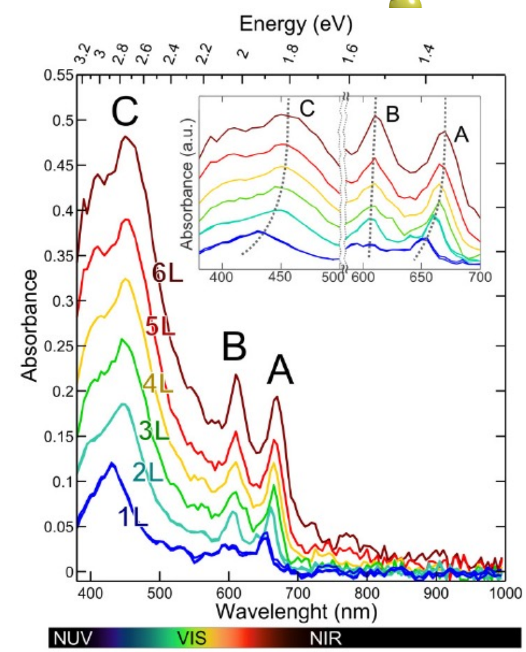
Time-resolved ARPES

Measuring Excitations





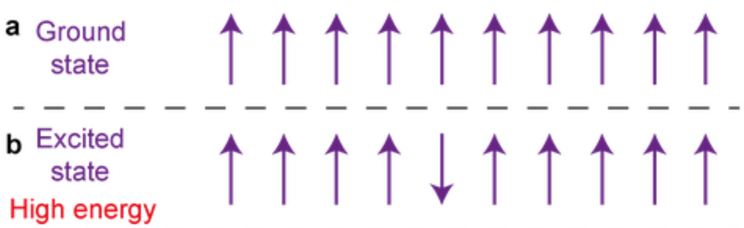




Measuring Excitations

Ising Model

$$\mathcal{H} = -J\sum_i \sigma_i^z \sigma_{i+1}^z + h_x \sum_i \sigma_i^x$$



Heisenberg model

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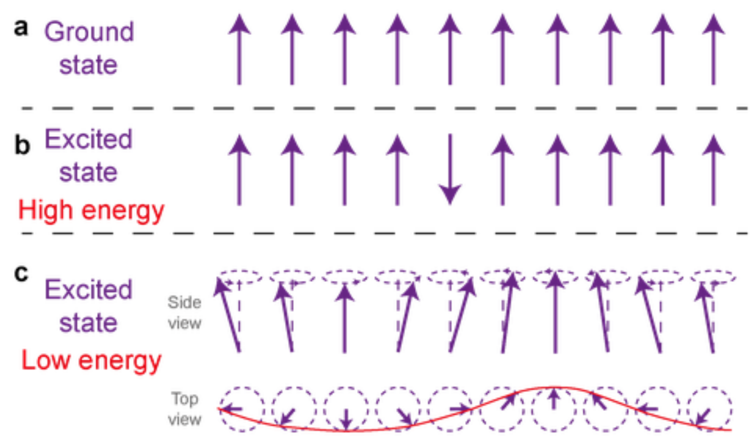

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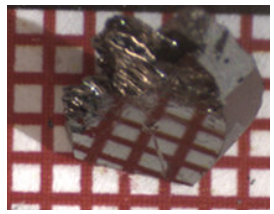
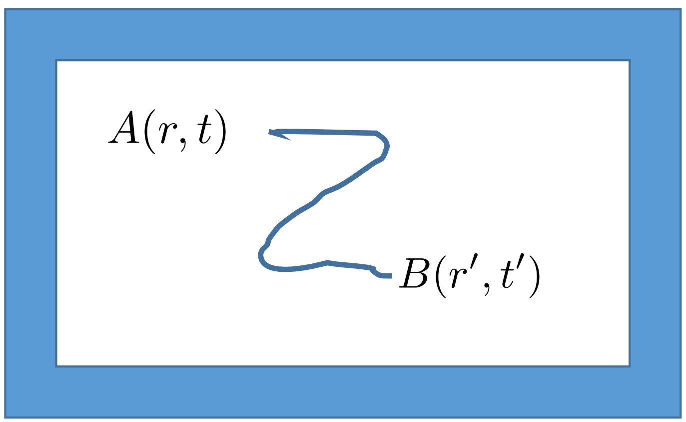
Quantum Computer = Quantum Simulator





$$\langle A(r,t)B(r',t')\rangle$$

Given some (observable) operator B at (r',t'), what is the likelihood of some (observable) operator A at (r,t)?

Optical conductivity, X-ray scattering, photoemission, etc.

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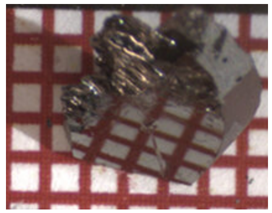
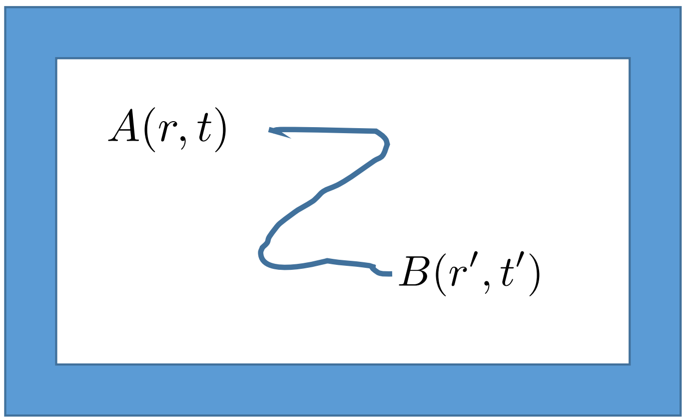
Quantum Computer = Quantum Simulator





$$e^{iE_0 t}\langle\phi_0|Be^{-i\mathcal{H}t}A|\phi_0\rangle$$

Interfere with ground state

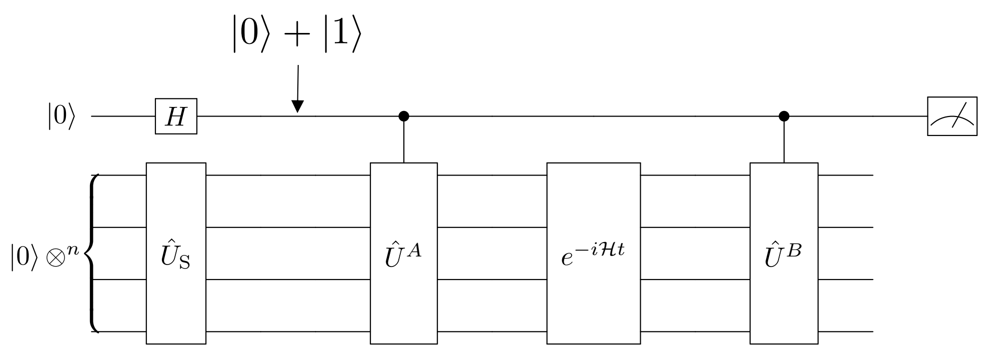
Complete expectation value

Apply excitation B

Time evolve

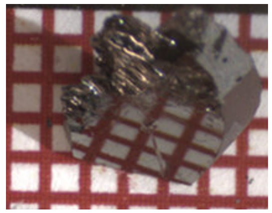
Apply excitation A

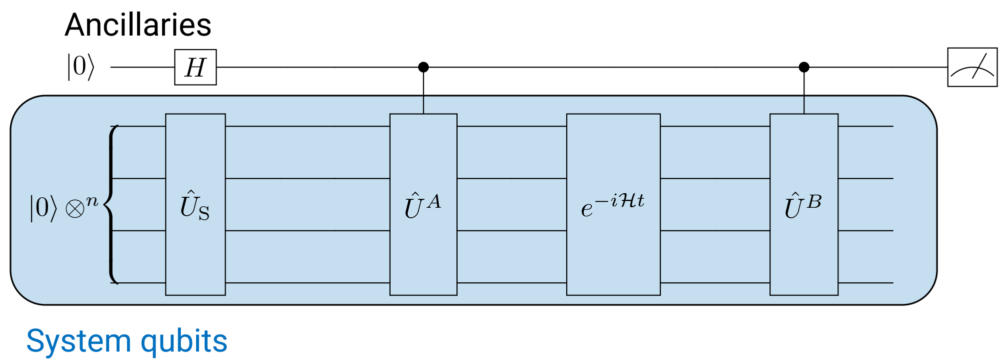
Prepare state of interest

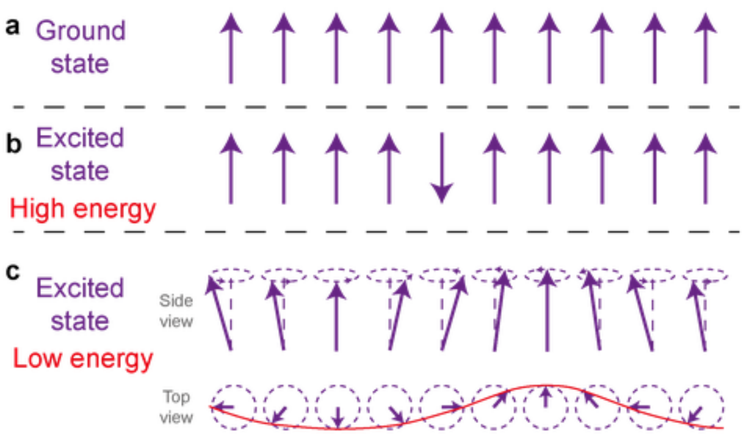


Somma, Simulating physical phenomena by quantum networks (2002)

Correlation functions







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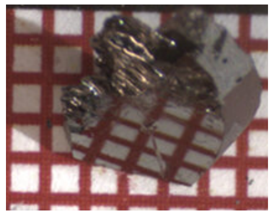
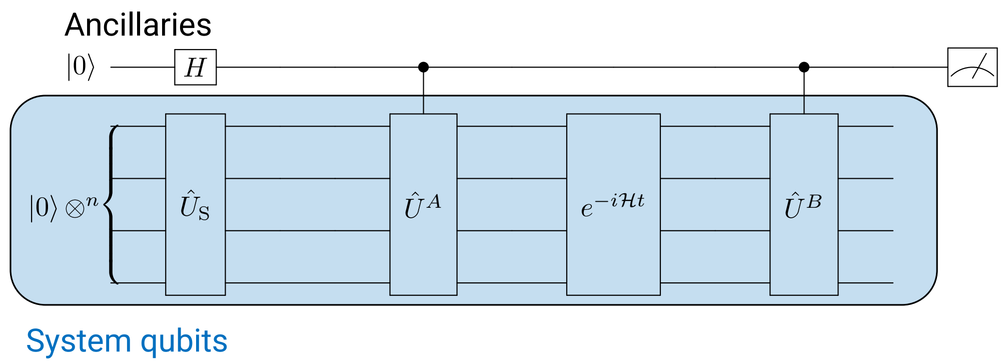
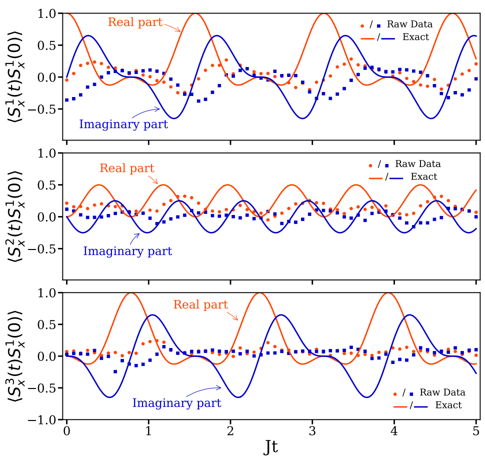
Correlation functions

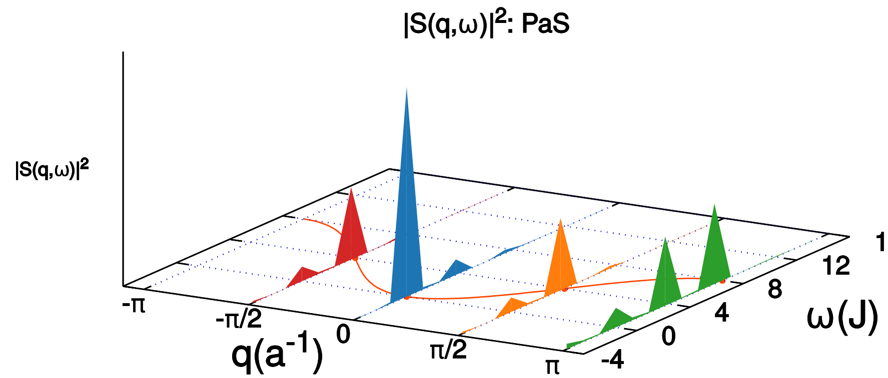




Raw data (2019)



Error mitigation

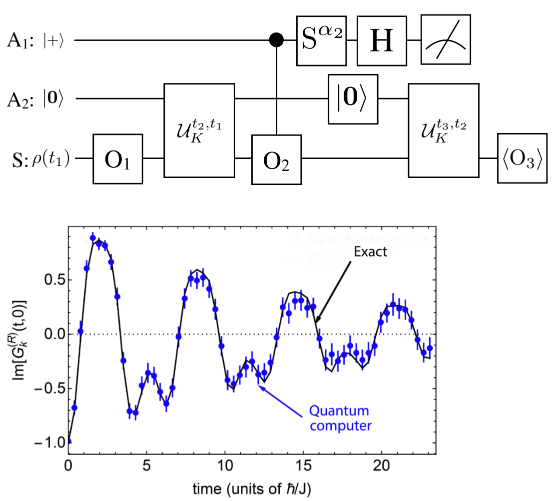


$$\langle A(r,t)B(r',t')\rangle$$

(A few) Quantum Algorithm(s) for correlation functions

Robust measurements of n-point correlation functions of driven-dissipative quantum systems on a digital quantum computer

Lorenzo Del Re,[1,2] Brian Rost,[1] Michael Foss-Feig,[3] A. F. Kemper,[4] and J. K. Freericks[1]
[1]Department of Physics, Georgetown University, 37th and O Sts., NW, Washington, DC 20057, USA
[2]Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany
[3]Quantinuum, 303 S. Technology Ct, Broomfield, Colorado 80021, USA
[4]Department of Physics, North Carolina State University, Raleigh, North Carolina 27695, USA
(Dated: April 27, 2022)



(Anti-)Commutators, open/dissipative

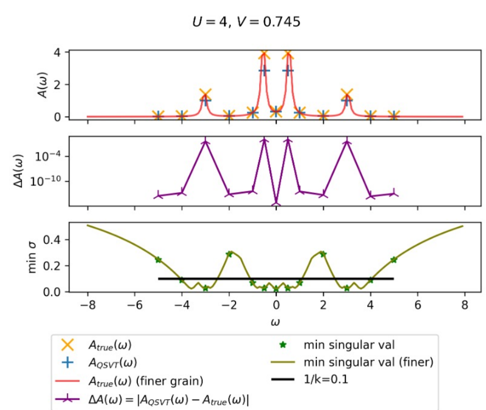
L. Del Re, B. Rost, M. Foss-Feig, AFK, J.K. Freericks
PRL 2024

Quantum Computed Green's Functions using a Cumulant Expansion of the Lanczos Method

Gabriel Greene-Diniz,[1,*] David Zsolt Manrique,[1] Kentaro Yamamoto,[2] Evgeny Plekhanov,[1] Nathan Fitzpatrick,[1] Michal Krompiec,[1] Rei Sakuma,[3] and David Muñoz Ramo[1]
[1]Quantinuum, Terrington House, 13-15 Hills Road, Cambridge CB2 1NL, UK
[2]Quantinuum K.K., Otemachi Financial City Grand Cube 3F, 1-9-2 Otemachi, Chiyoda-ku, Tokyo, Japan
[3]Materials Informatics Initiative, RD Technology & Digital Transformation Center, JSR Corporation, 3-103-9, Tonomachi, Kawasaki-ku, Kawasaki, 210-0821, Kanagawa, Japan.
(Dated: September 19, 2023)

Calculating the Single-Particle Many-body Green's Functions via the Quantum Singular Value Transform Algorithm

Alexis Ralli,[1,2,*] Gabriel Greene-Diniz,[1] David Muñoz Ramo,[1] and Nathan Fitzpatrick[1,†]
[1]Quantinuum
13-15 Hills Road, CB2 1NL Cambridge
United Kingdom
[2]Centre for Computational Science
Department of Chemistry, University College London, WC1H 0AJ
United Kingdom
(Dated: July 26, 2023)



PRL 111, 147205 (2013) PHYSICAL REVIEW LETTERS week ending 4 OCTOBER 2013

Probing Real-Space and Time-Resolved Correlation Functions with Many-Body Ramsey Interferometry

Michael Knap,[1,2,*] Adrian Kantian,[3] Thierry Giamarchi,[3] Immanuel Bloch,[4,5] Mikhail D. Lukin,[1] and Eugene Demler[1]
[1]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA
[2]ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138, USA
[3]DPMC-MaNEP, University of Geneva, 24 Quai Ernest-Ansermet CH-1211 Geneva, Switzerland
[4]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany
[5]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany
(Received 2 July 2013; revised manuscript received 18 September 2013; published 4 October 2013)

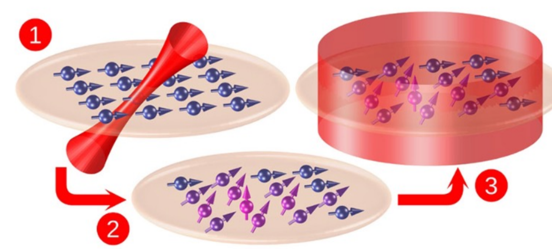


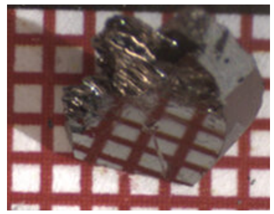
FIG. 1 (color online). Many-body Ramsey interferometry consists of the following steps: (1) A spin system prepared in its ground state is locally excited by $\pi/2$ rotation; (2) the system evolves in time; (3) a global $\pi/2$ rotation is applied, followed by the measurement of the spin state. This protocol provides the dynamic many-body Green's function.

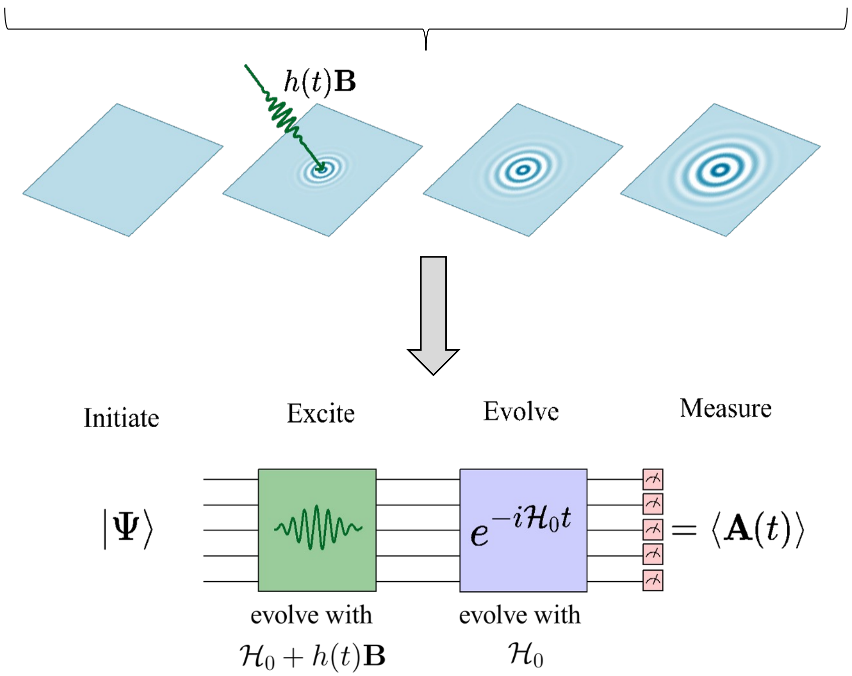
Commutators

10.1103/PhysRevLett.111.147205

Linear Response

Nature Communications 15, 3881 (2024)





A linear response framework for simulating bosonic and fermionic correlation functions illustrated on quantum computers

Efekan Kökcü,[1] Heba A. Labib,[1] J. K. Freericks,[2] and A. F. Kemper[1,*]

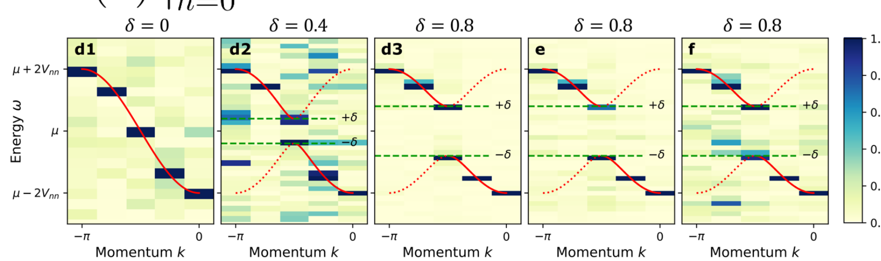
[1] *Department of Physics, North Carolina State University, Raleigh, North Carolina 27695, USA*
[2] *Department of Physics, Georgetown University, 37th and O Sts. NW, Washington, DC 20057 USA*

(Dated: February 22, 2023)

1. Make the excitation part of the quantum simulation

2. Post-process the data to get the response functions

$$\left.\frac{\delta A(t)}{\delta h(t')}\right|_{h=0} = -i\theta(t-t')\langle\psi_0|[\mathbf{A}(t), \mathbf{B}(t')]|\psi_0\rangle$$

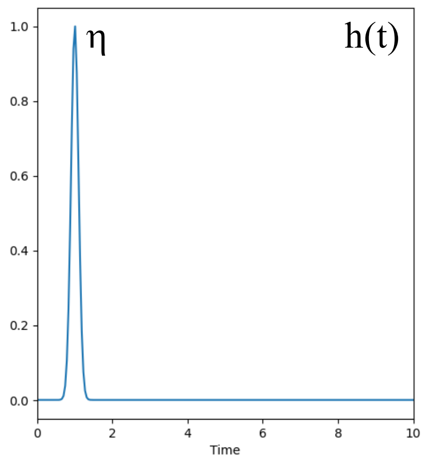


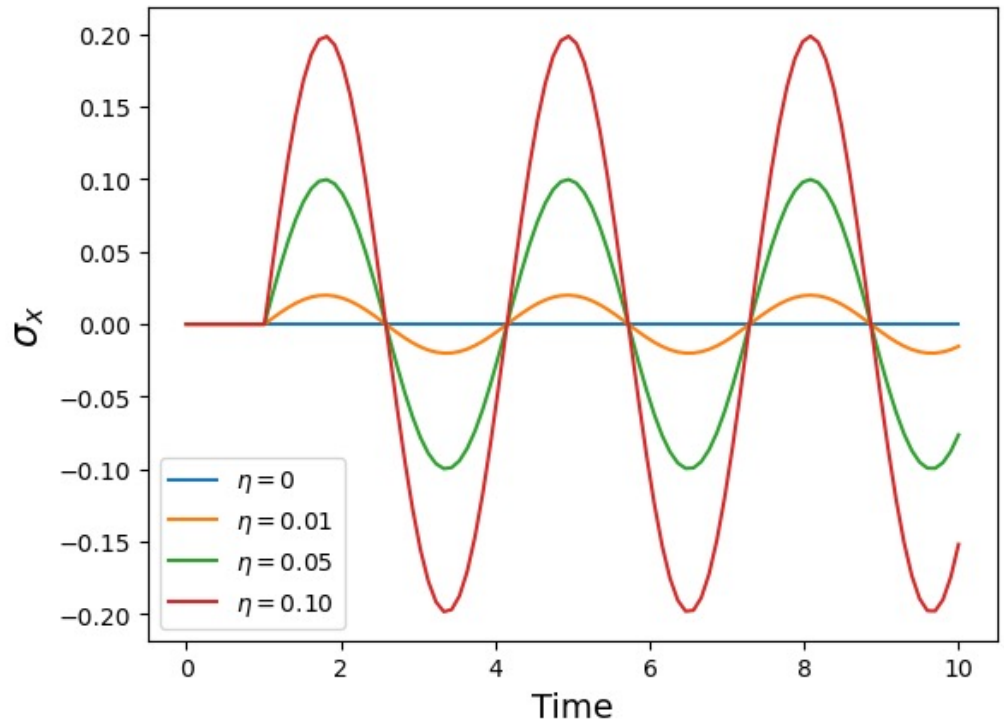
Linear Response

A simple example: single spin with energy level difference = 2

$$\mathbf{H}_0 = \sigma^z$$

$$\mathbf{A} = \mathbf{B} = \sigma^x$$





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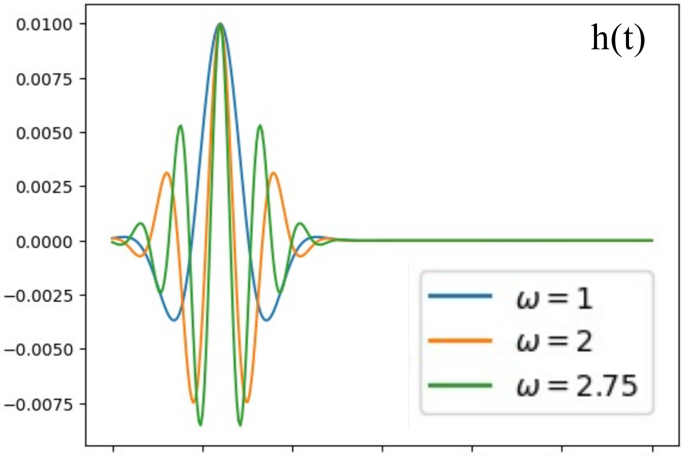
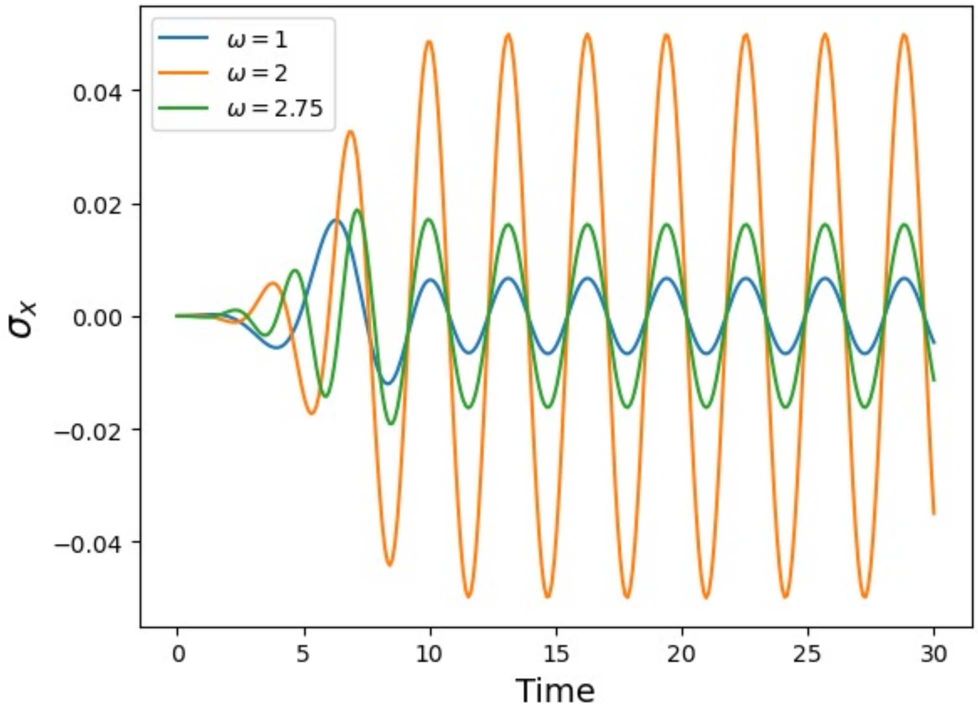


Frequency



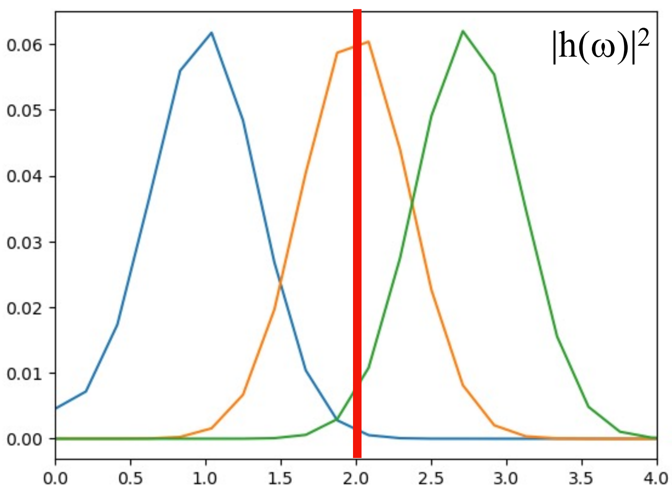
NC STATE UNIVERSITY

Linear Response

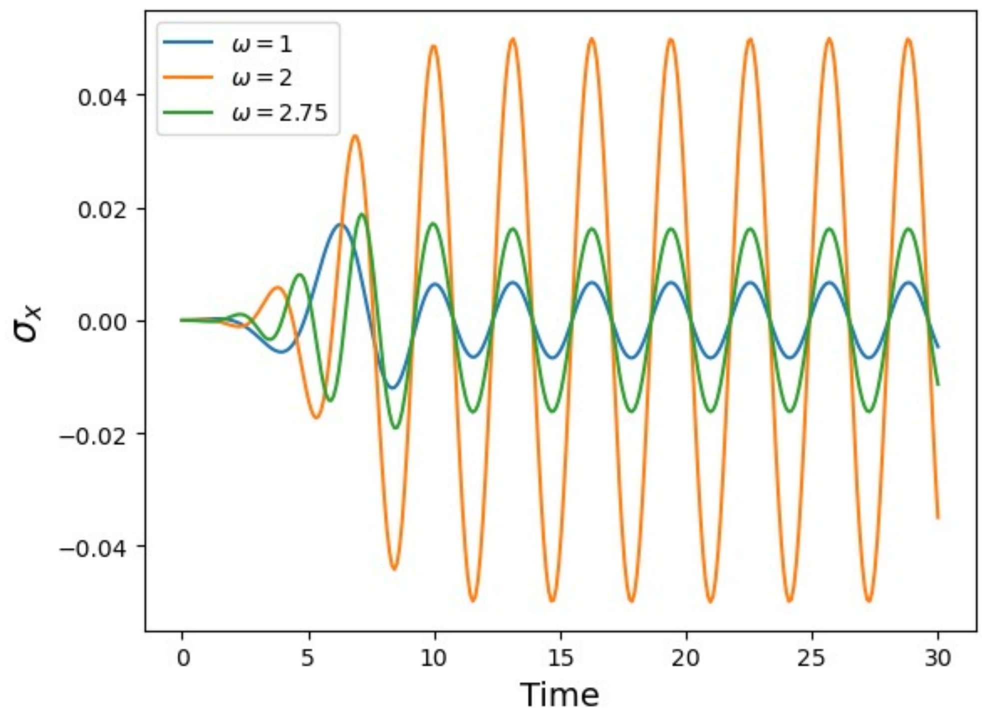
A simple example: single spin with energy level difference = 2

$$\mathbf{H}_0 = \sigma^z$$

$$\mathbf{A} = \mathbf{B} = \sigma^x$$



Frequency



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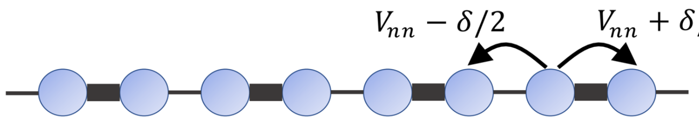
Linear Response -> Green's function

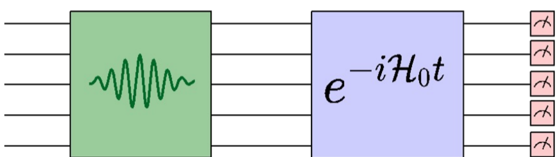
Su-Schrieffer-Heeger model for polyacetylene



$$\mathcal{H}_0 = -\sum_{\langle i,j \rangle} \left[V_{nn} + (-1)^i \, \delta/2 \right] c_i^\dagger c_j - \mu \sum_i c_i^\dagger c_i$$

Initiate Excite Evolve Measure

$|\Psi\rangle$

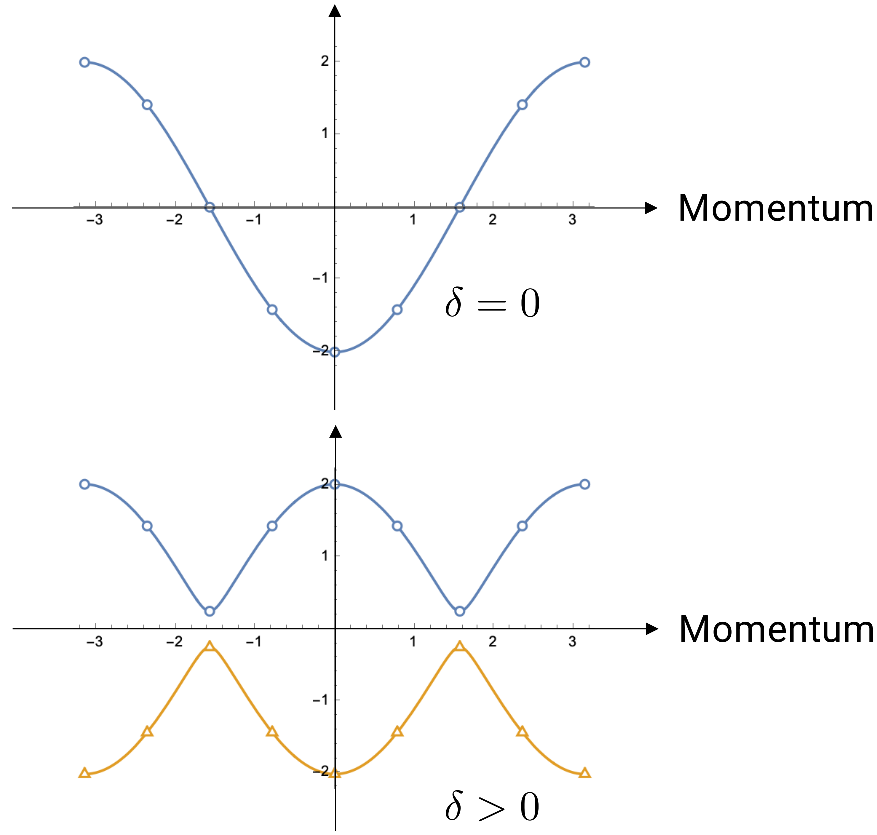


$= \langle \mathbf{A}(t) \rangle$

evolve with $\mathcal{H}_0 + h(t)\mathbf{B}$

evolve with $\mathcal{H}_0$

$$G^R(r_i, t; r_j, t') = -i\theta(t - t') \, \langle \psi_0 | \{ c_i(t), c_j^\dagger(t') \} | \psi_0 \rangle$$



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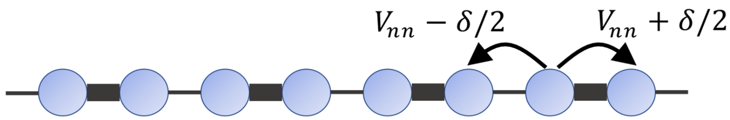

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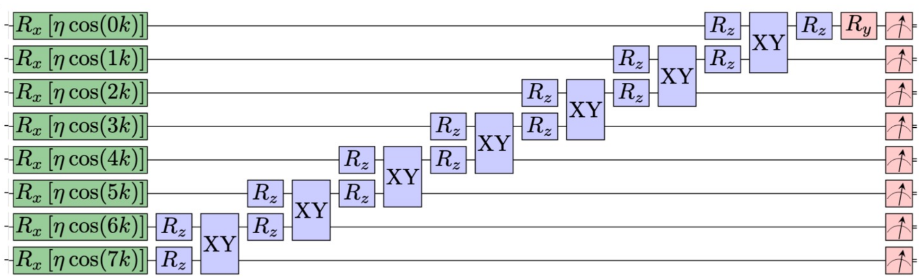
Compressed circuit run on *ibm_auckland*



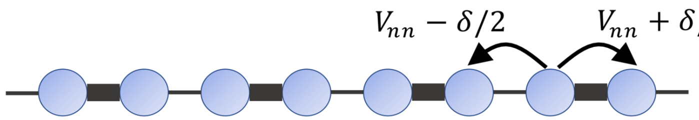
$$\mathbf{B} = \sum_i 2\cos(kr_i) \left[c_i + c_i^\dagger \right]$$

Choose **B** to create a momentum eigenstate

$$G_k^R(t) = -i\theta(t) \langle \psi_0 | \{ c_k(t), c_k^\dagger(0) \} | \psi_0 \rangle$$

Linear Response

Su-Schrieffer-Heeger model for polyacetylene



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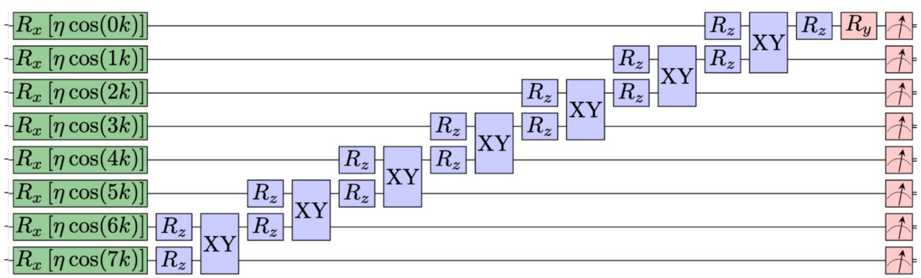

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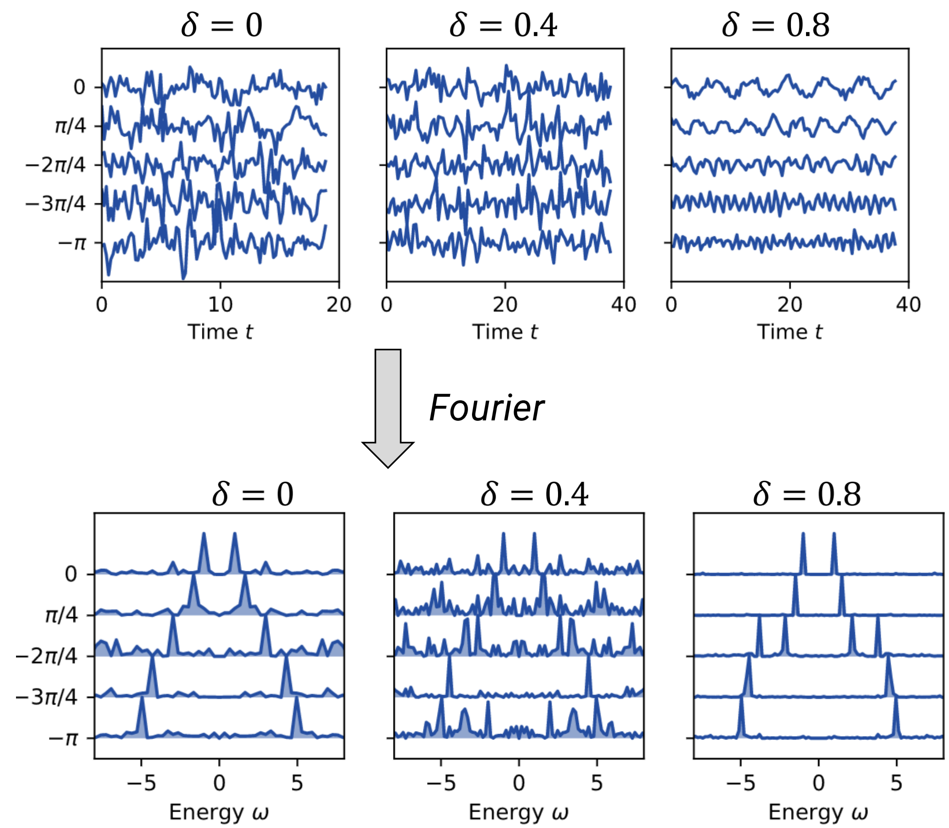

Linear Response

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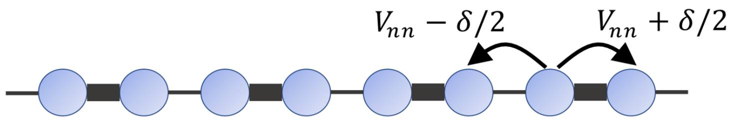
Su-Schrieffer-Heeger model for polyacetylene



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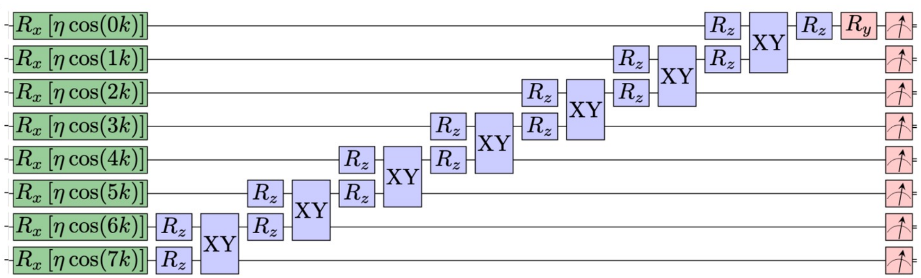

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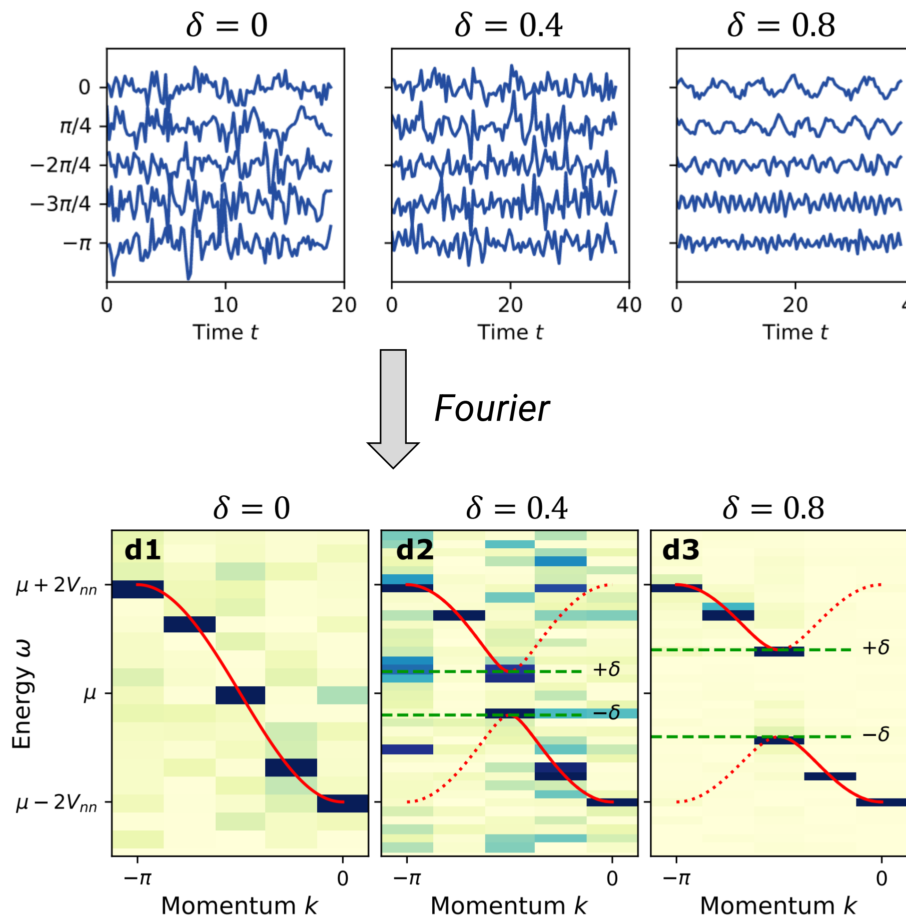

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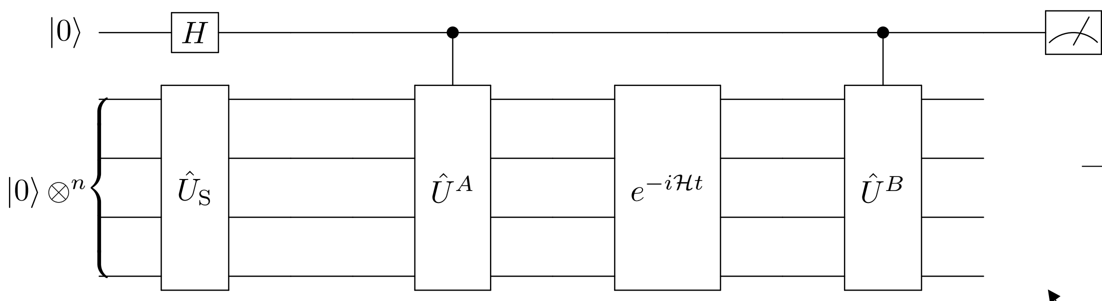
A-Z quantum simulation



Classical post-processing techniques

Prepare state of interest

Time evolve

Dynamical response functions

- *Physics-Informed Subspace Expansions*
- *Barren optimization plateaus*

- *Lie-algebraic methods for time evolution*
- *Open quantum system evolution*

- *Correlation functions*
- *Open quantum system Green's functions*
- *Dynamical Mean Field Theory*

A-Z quantum simulation

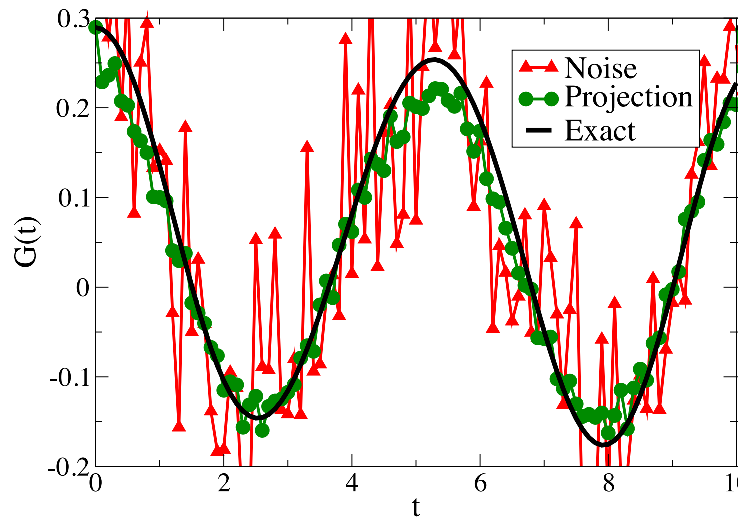
- It turns out that these are positive semi-definite (PSD) functions:

$$G_{AA}(t-t') = \mathrm{Tr}\left[\rho A(t)^\dagger A(t')\right]$$

- Then this is a PSD matrix:

$$\underline{\mathrm{G}} = \begin{pmatrix} f_0 & f_1 & f_2 & \cdots & f_n \\ f_1^* & f_0 & f_1 & \cdots & f_{n-1} \\ f_2^* & f_1^* & f_0 & \cdots & f_{n-2} \\ \vdots & & & \ddots & \vdots \\ f_n^* & f_{n-1}^* & f_{n-2}^* & \cdots & f_0 \end{pmatrix}$$

where $G_{AA}(t_i - t_j) \to f_{i-j}$



A.F. Kemper et al., PRL (2024)

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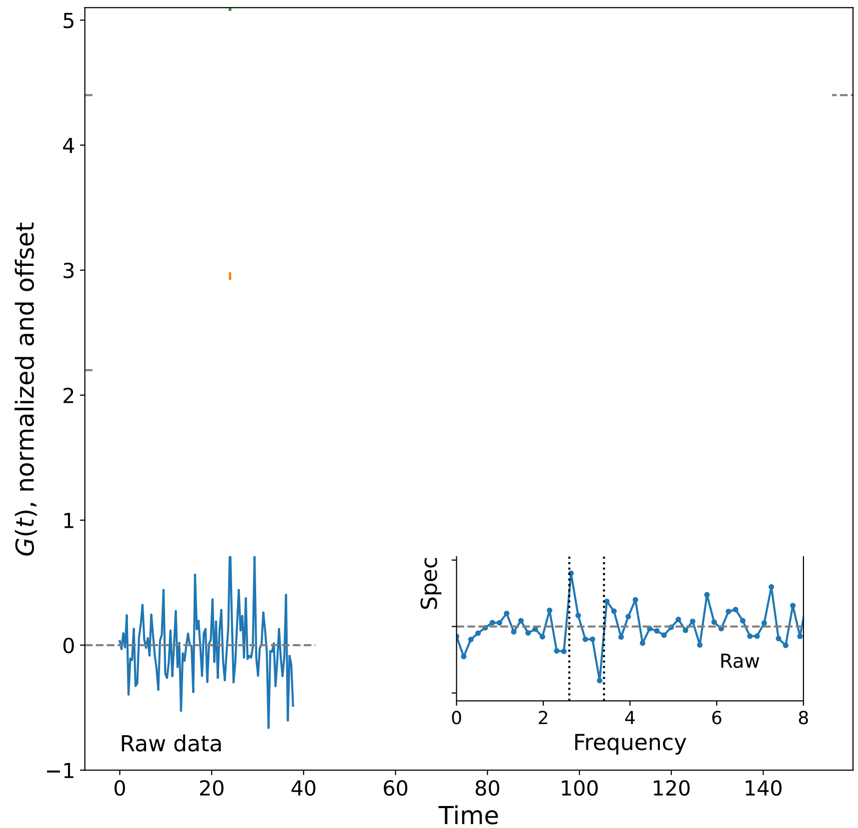

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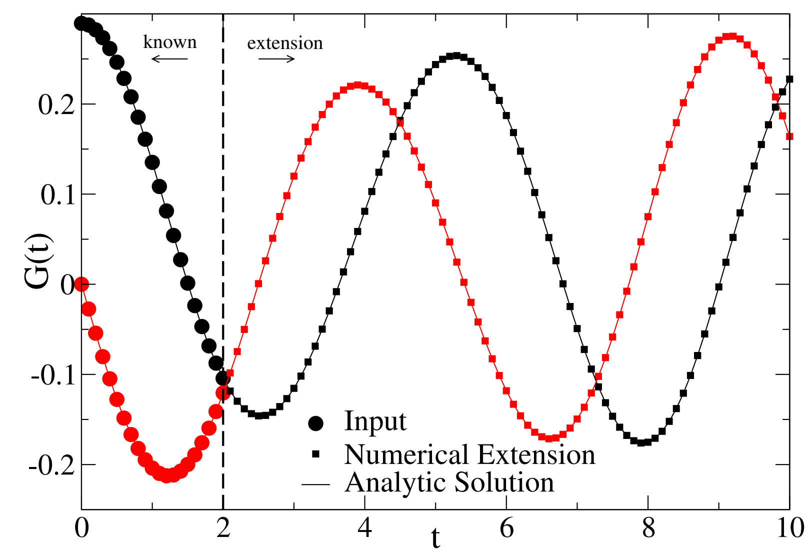

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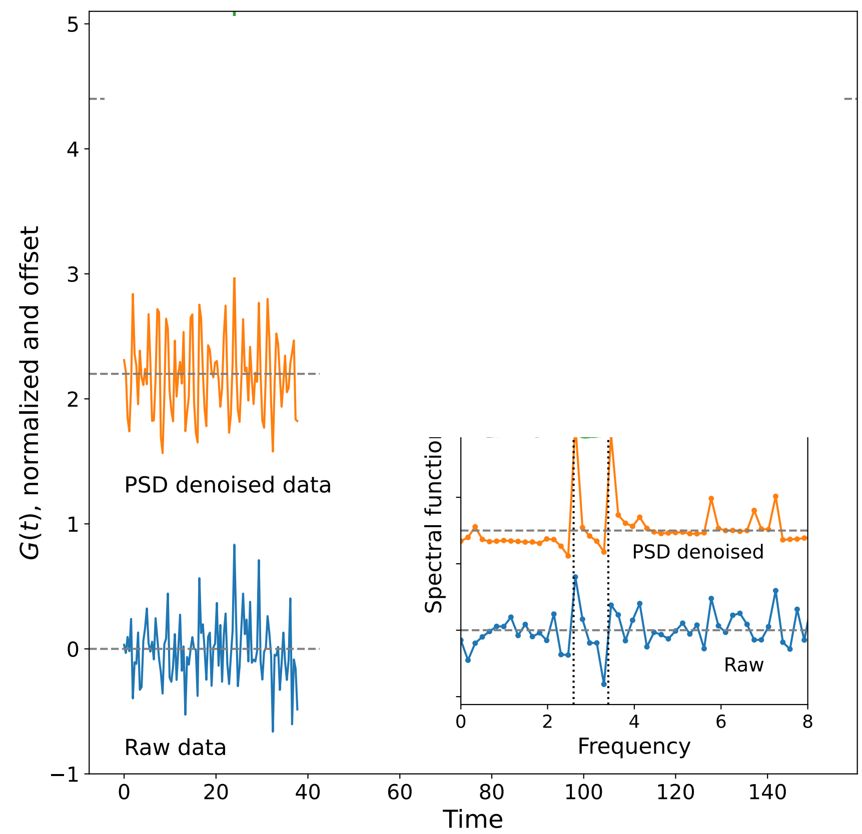


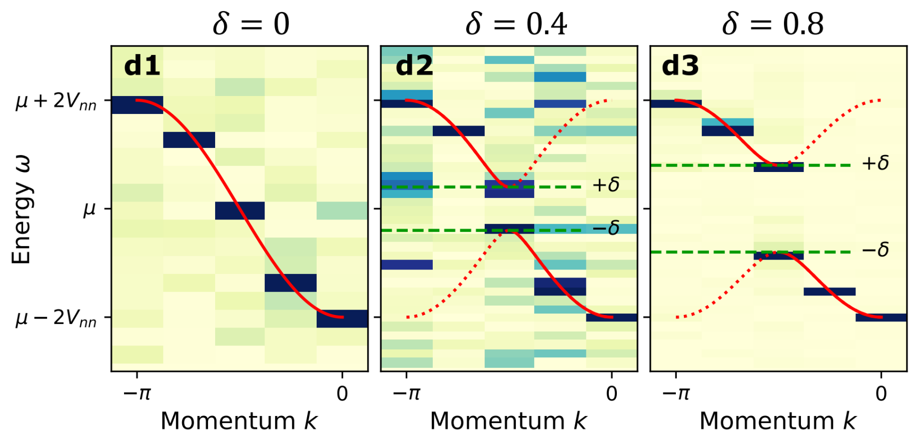
A.F. Kemper et al., PRL (2024)

Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

Received May 7, 1981



1. Can classical physics be simulated by a classical computer? ✓
2. Can quantum physics be simulated by a classical computer? ?
3. Can physics be simulated by a quantum computer? ✓

Brief outline

- Quantum Matter meets Quantum Computing
- Response functions
  - Why we care
  - How do find them
- A different paradigm: Making the experiment part of the simulation via linear response
- Beyond Quantum Simulation

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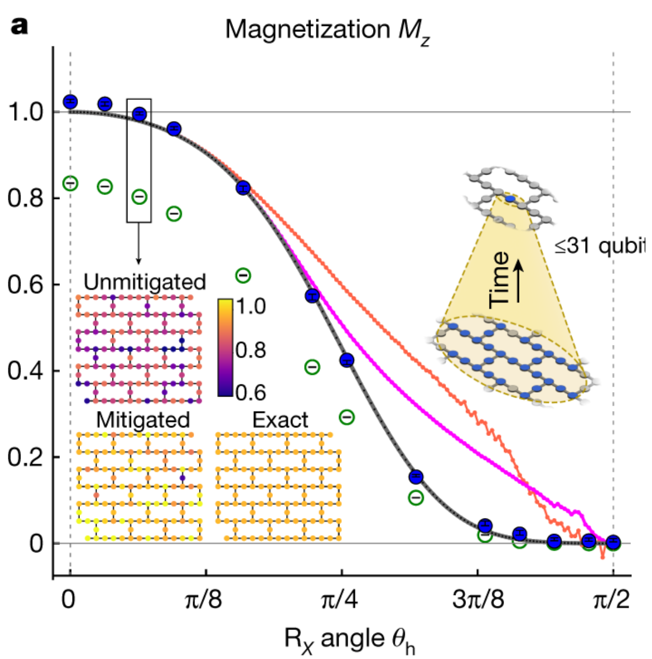
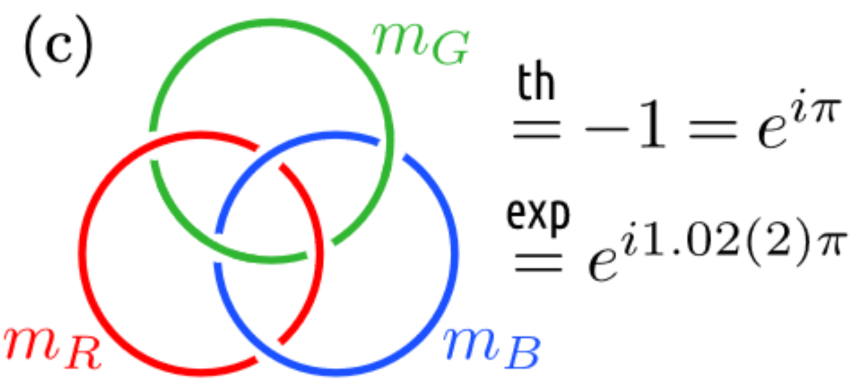
Bespoke quantum simulator — *Digital algorithms*



“Evidence for the utility of quantum computing before fault tolerance” 10.1038/s41586-023-06096-3



“Creation of Non-Abelian Topological Order and Anyons on a Trapped-Ion Processor,” arXiv:2305.03766.

Bespoke quantum simulator — Digital algorithms

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Schor's algorithm
Integer factorization
Linear solvers (HHL)
Quantum Adiabatic Optimization
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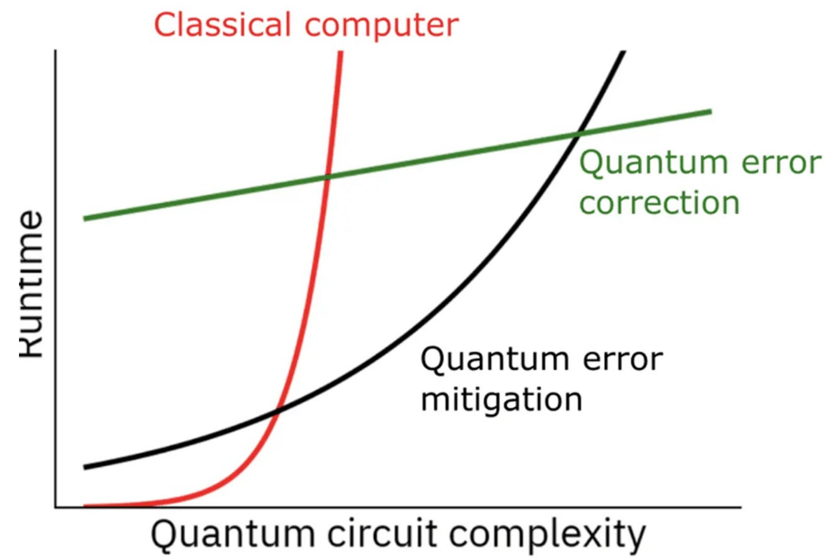

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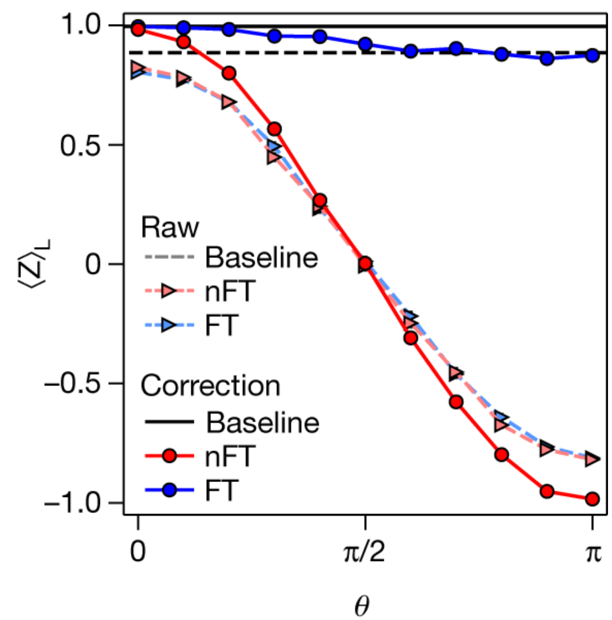

"Fault-tolerant control of an error-corrected qubit"
10.1038/s41586-021-03928-y

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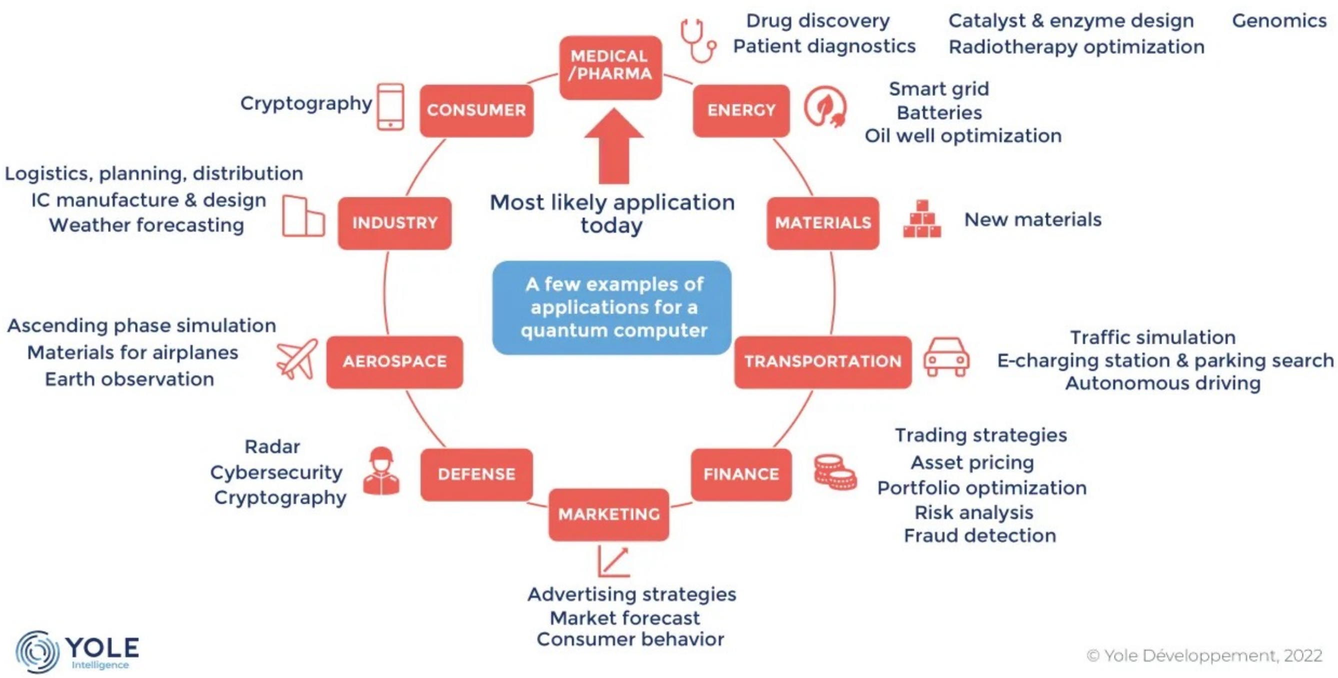
QUANTUM COMPUTING – MULTIPLE COMPLEX PROBLEMS IN MULTIPLE MARKETS

Source: Quantum Technologies report, Yole Développement, 2021



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frontiers in PHYSICS

REVIEW ARTICLE
published: 12 February 2014
doi: 10.3389/fphy.2014.00005

Ising formulations of many NP problems

Andrew Lucas*

Lyman Laboratory of Physics, Department of Physics, Harvard University, Cambridge, MA, USA

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Ryan Babbush, Harvard University, USA
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***Correspondence:**
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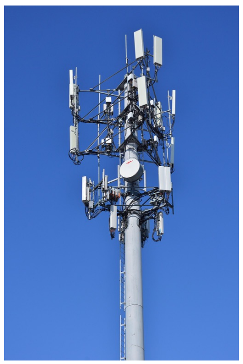
e-mail: lucas@fas.harvard.edu

We provide Ising formulations for many NP-complete and NP-hard problems, including all of Karp's 21 NP-complete problems. This collects and extends mappings to the Ising model from partitioning, covering, and satisfiability. In each case, the required number of spins is at most cubic in the size of the problem. This work may be useful in designing adiabatic quantum optimization algorithms.

Keywords: spin glasses, complexity theory, adiabatic quantum computation, NP, algorithms

Problems with an unreasonably large solution space



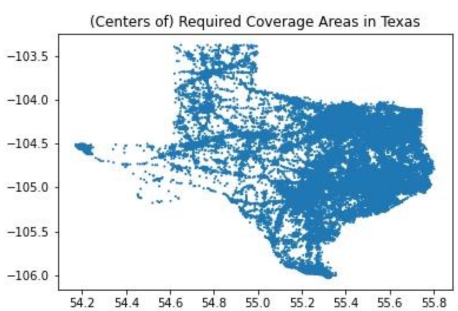
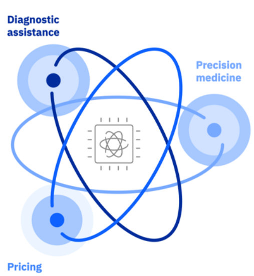
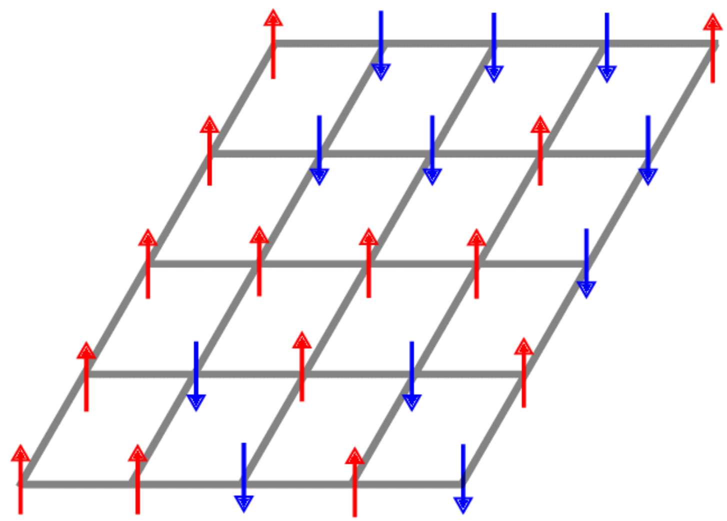


Figure 1
Quantum computers may enable three key healthcare use cases that reinforce each other in a virtuous cycle. For instance, accurate diagnoses enable precise treatments, as well as a better reflection of patient risks in pricing models.



Ising Model

$$\mathcal{H} = -J\sum_i \vec{\sigma}_i \cdot \vec{\sigma}_{i+1} + h_x \sum_i \sigma_i^x$$



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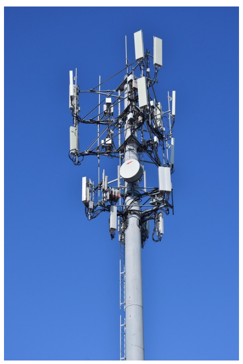

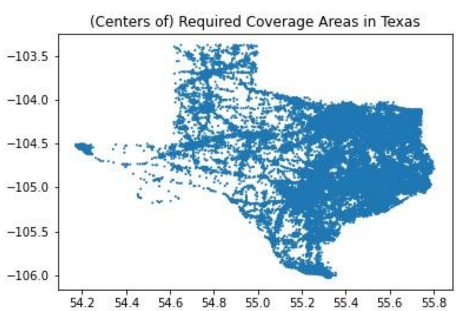

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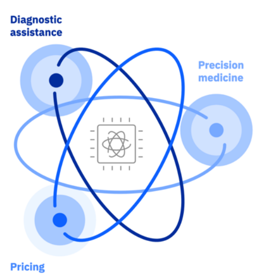


Variational algorithms

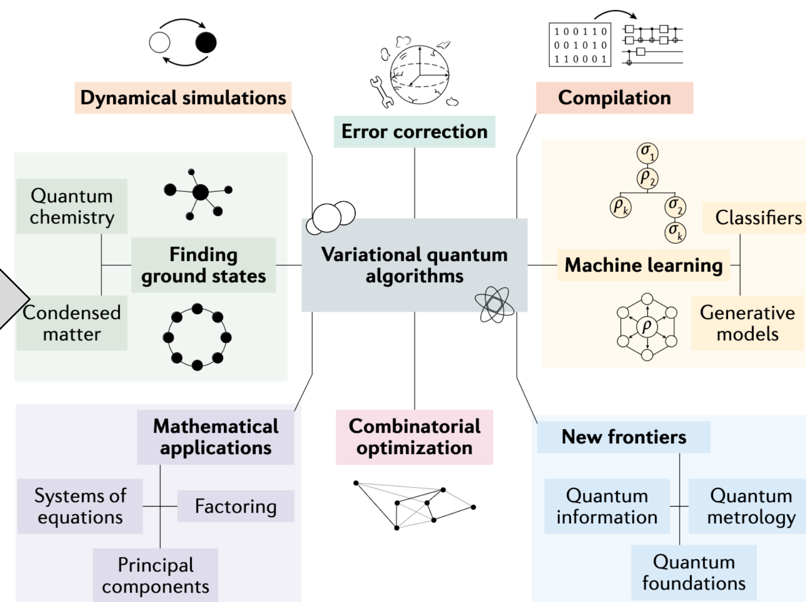
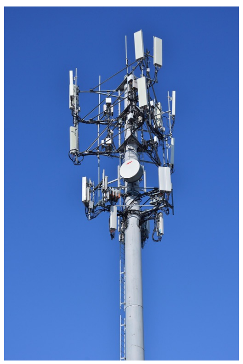
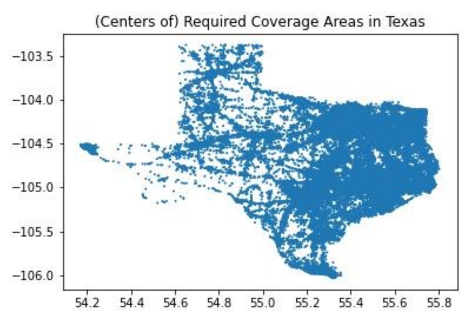


Fig. 1 | **Applications of variational quantum algorithms.** Many applications have been envisaged for variational quantum algorithms. Here we show some of the key applications that are discussed in this Review.

Problems with an unreasonably large solution space





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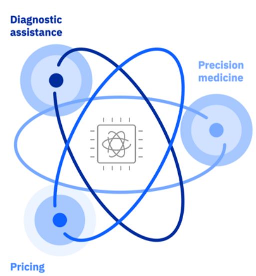
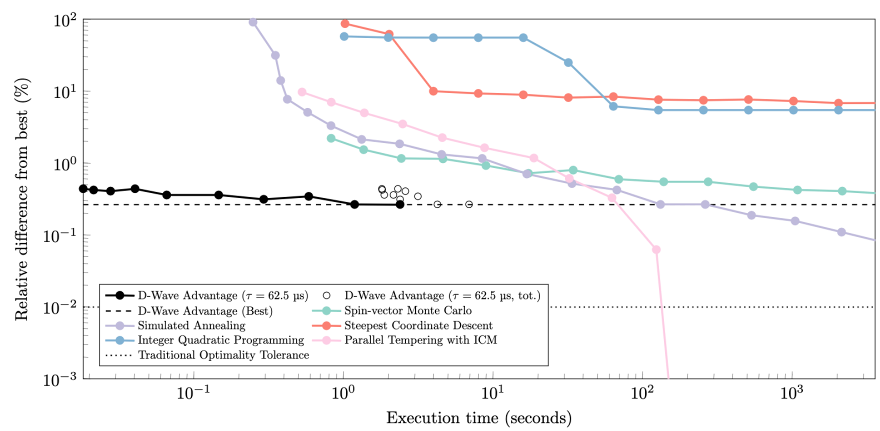


On the Emerging Potential of Quantum Annealing Hardware for Combinatorial Optimization

Byron Tasseff
Los Alamos National Laboratory, Los Alamos, NM 87545

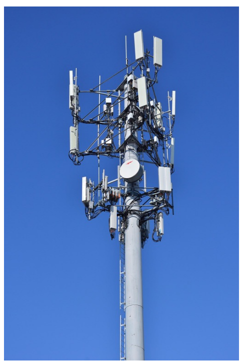
Tameem Albash
University of New Mexico, Albuquerque, NM 87131

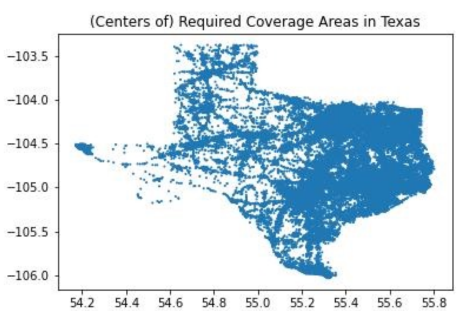
Zachary Morrell, Marc Vuffray, Andrey Y. Lokhov, Sidhant Misra, Carleton Coffrin*
Los Alamos National Laboratory, Los Alamos, NM 87545



Why quantum computing?

Problems with an unreasonably large solution space





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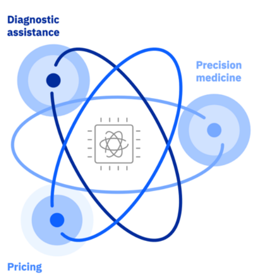
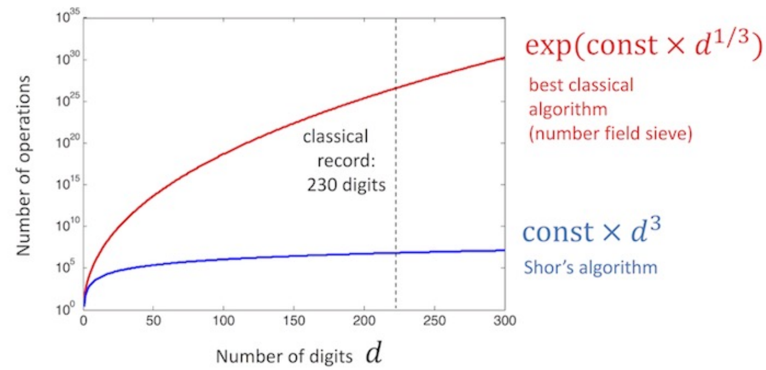
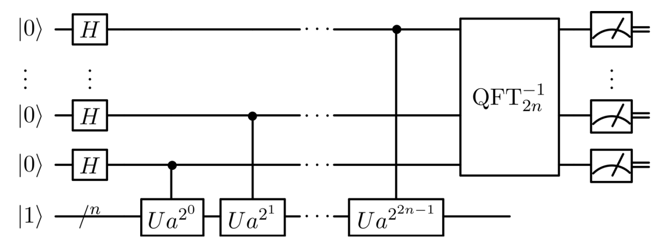


Efficient algorithms

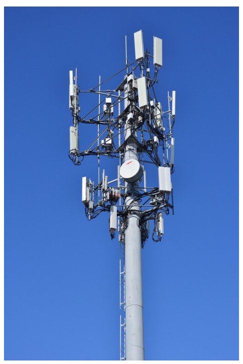


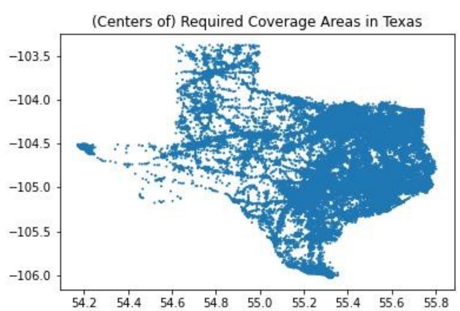


https://quantum-computing.ibm.com/

Why quantum computing?

Problems with an unreasonably large solution space





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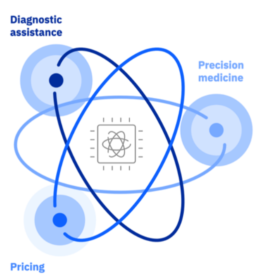
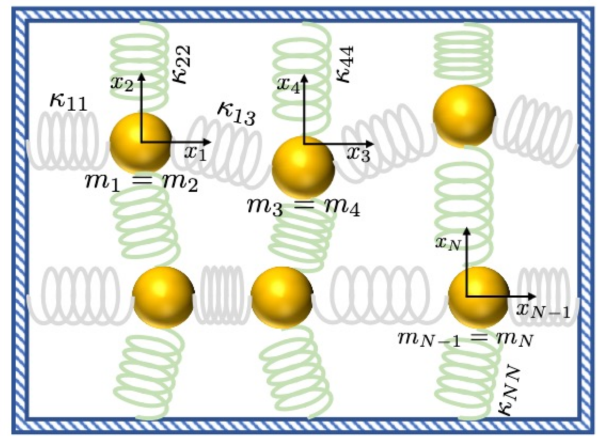


Efficient algorithms

Exponential quantum speedup in simulating coupled classical oscillators

Ryan Babbush,[1] Dominic W. Berry,[2] Robin Kothari,[1] Rolando D. Somma,[1] and Nathan Wiebe[3,4,5]



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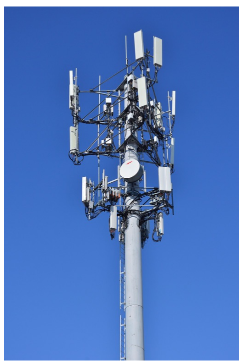
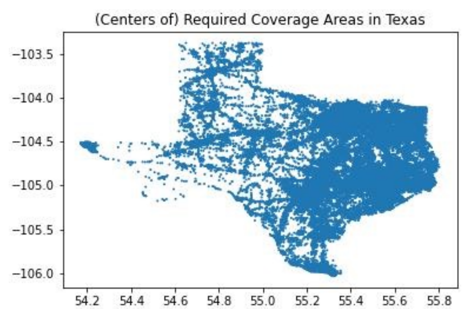
Why quantum computing?

Problems with an unreasonably large solution space





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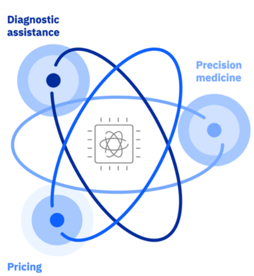

Efficient algorithms

A quantum algorithm for the linear Vlasov equation with collisions

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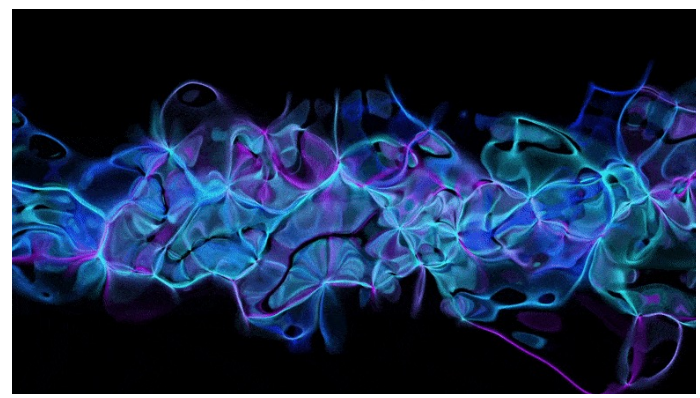
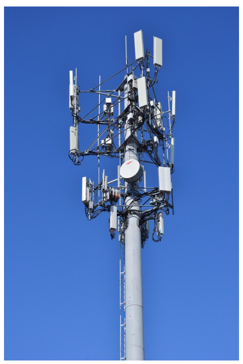
(Dated: March 8, 2023)



Why quantum computing?

Problems with an unreasonably large solution space



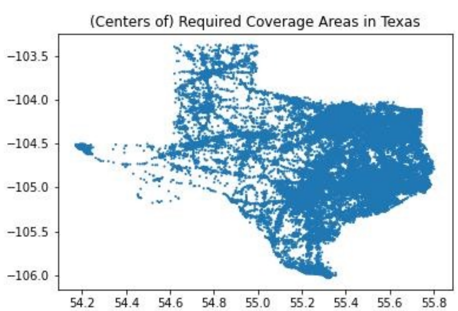
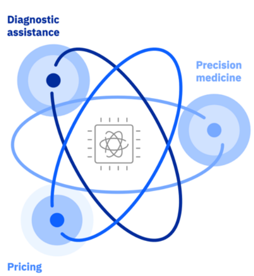
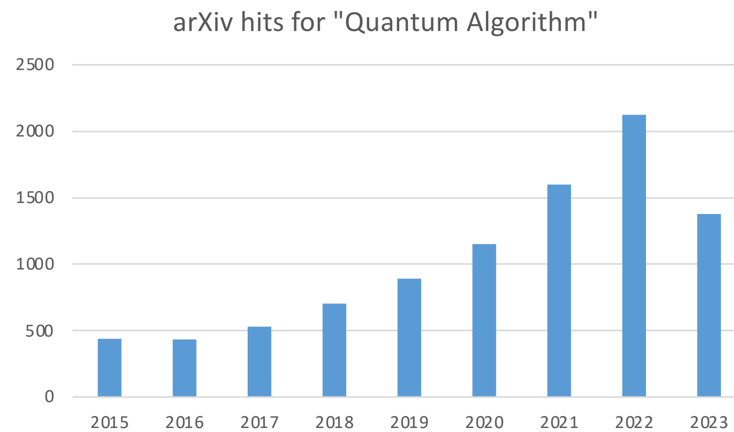


Figure 1
Quantum computers may enable three key healthcare use cases that reinforce each other in a virtuous cycle. For instance, accurate diagnoses enable precise treatments, as well as a better reflection of patient risks in pricing models.



Efficient algorithms



(data from June 2023)

NC STATE UNIVERSITY

Simulating Physics with Computers

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Received May 7, 1981

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2. Can quantum physics be simulated by a classical computer?
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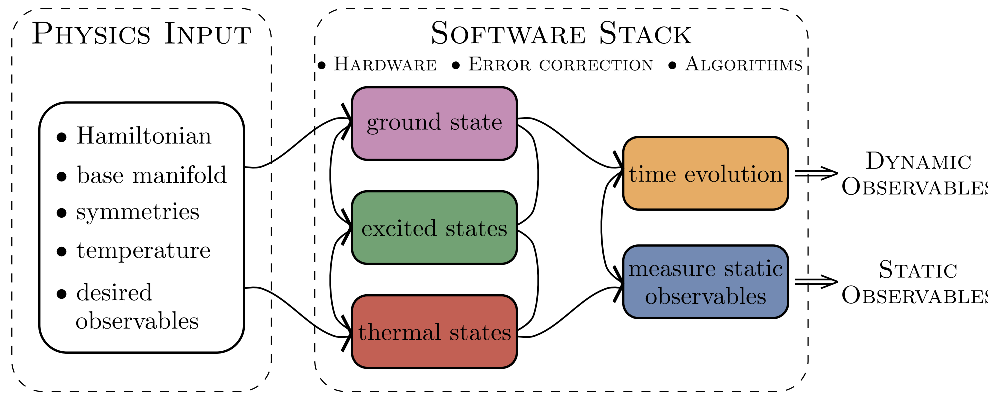

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