



QUANTUM COMPUTING



Quantum Computing Systems - expectations

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HOW'S YOUR
QUANTUM COMPUTER
PROTOTYPE COMING
ALONG?

GREAT!



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THE PROJECT EXISTS
IN A SIMULTANEOUS
STATE OF BEING BOTH
TOTALLY SUCCESSFUL
AND NOT EVEN
STARTED.



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CAN I
OBSERVE
IT?

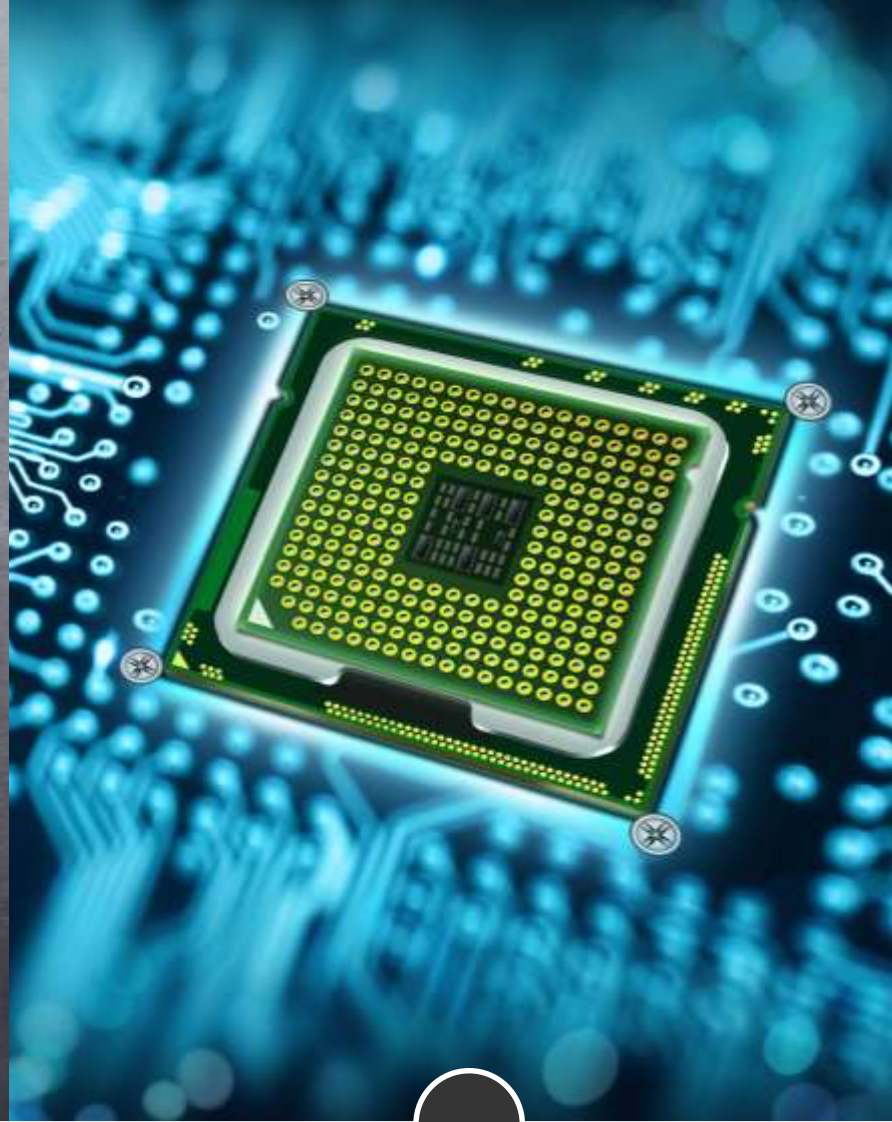
THAT'S
A TRICKY
QUESTION.







2500
BC



20th
Century



21st
Century

30 qubits → 16 Gb

40 qubits → 16 Tb

50 qubits → 16 Pb

Exponential Scaling





Simulating 260 qubits
requires more memory than
there are atoms in the universe

Addressing classically intractable problems

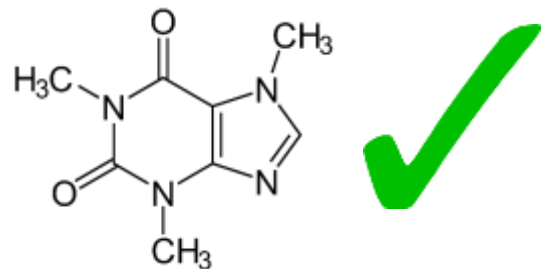
Classical

Quantum

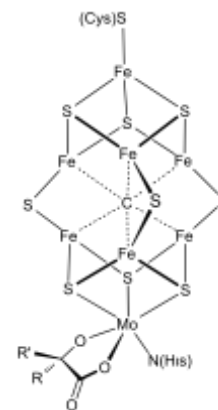
1 billion
years

100 seconds

RSA-2048
Challenge
Problem

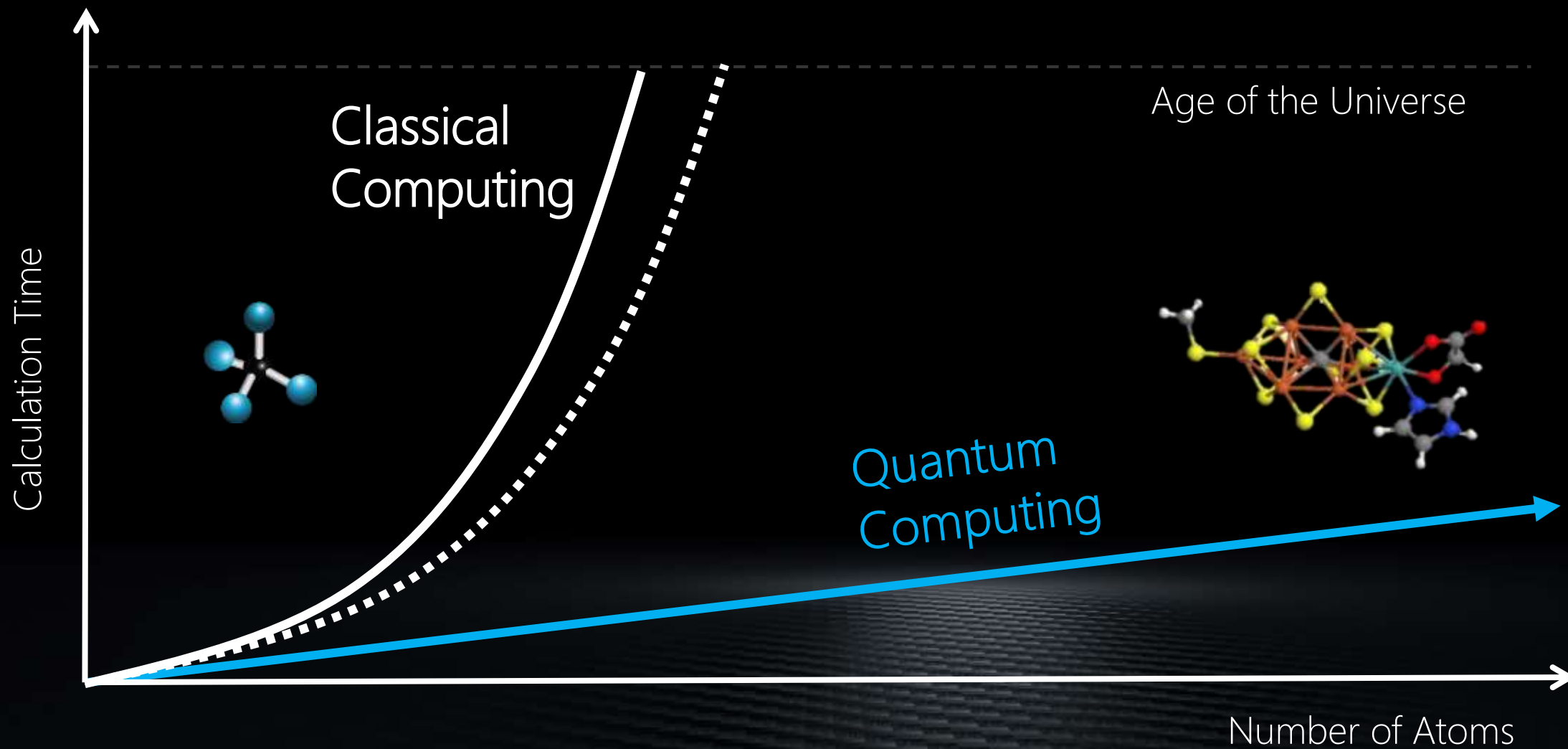


CAFFEINE MOLECULE

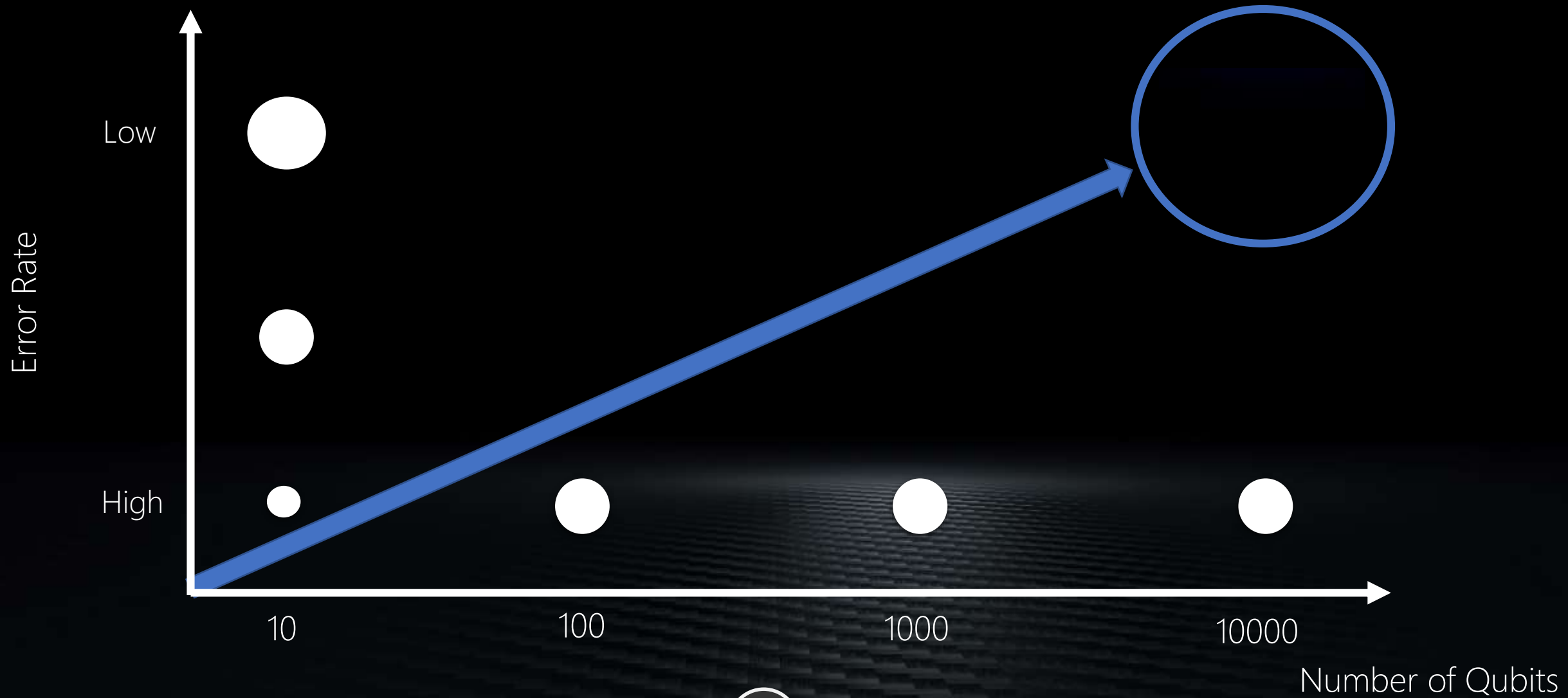


FEMOCO MOLECULE

The fastest supercomputer
in the world



Addressing classically intractable problems




All qubits are not created equal

Majorana Fermions

Predicted by Ettore Majorana
in 1937



Thurston
... for circle
...
Unique upto $SL(2, \mathbb{C})$



fixes up
 i th vertex

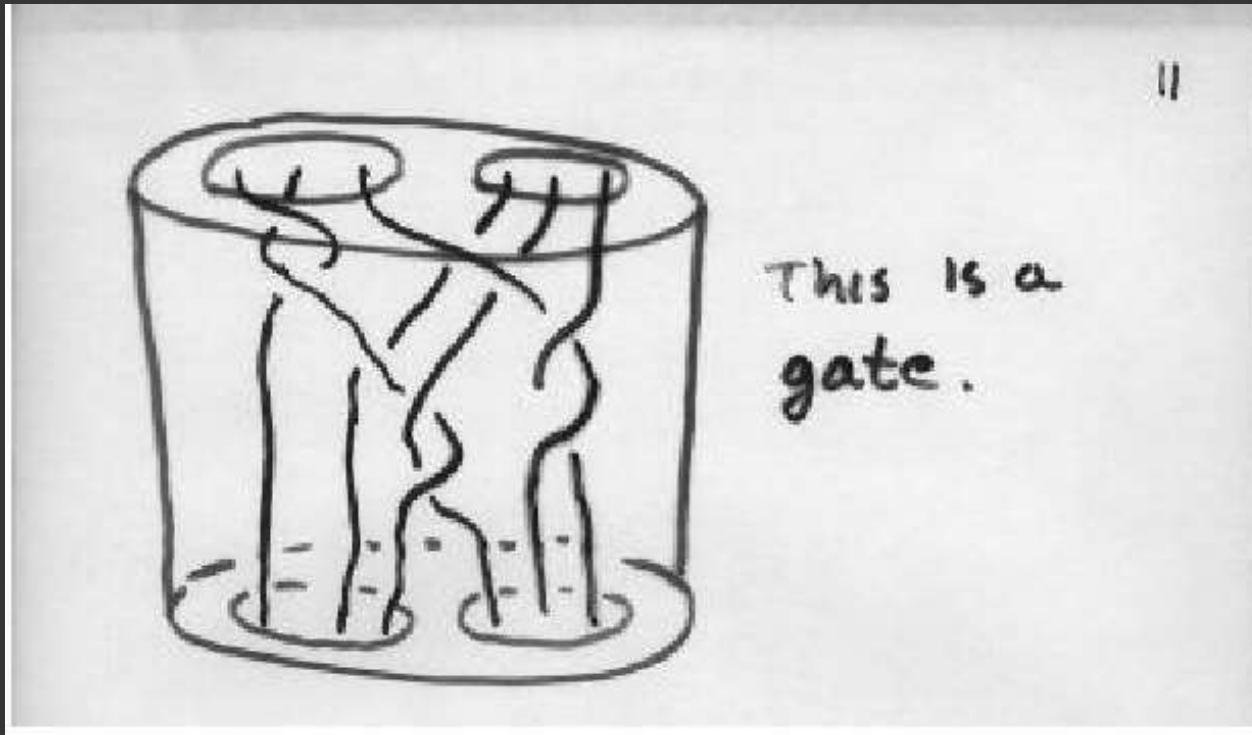


$l_i = r_i + t_i$



2000

Inspiration



From “A topological modular functor which is universal for quantum computation”

Talk given by
Michael Freedman at
“[Mathematics of Quantum Computation](#)”,
MSRI, Feb. 2000
(available online).

STATION

Q

The chalkboard contains several mathematical notes and a diagram:

- Left side:** $\frac{P(h, m, p)}{1}$ and \sum_{abc}
- Middle:** $\delta \phi \delta m, \omega^2 P_2(\cdot)$ and a tree diagram with nodes and edges.
- Right side:** E , $L \rightarrow L_0$, $L \rightarrow 10$, $L \rightarrow 10$, $j(z)$, $4 \langle f'(z) f'(0) \rangle$, and $\langle f'(z) f'(0) \rangle$.



Science

25 May 2012 | \$16

AAAS

“

MAJORANA PARTICLE
GLIMPSED IN LAB.

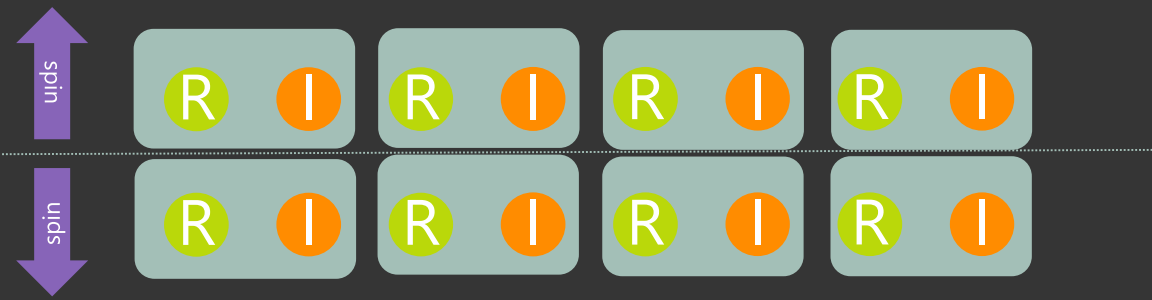
”

BBC NEWS



2012

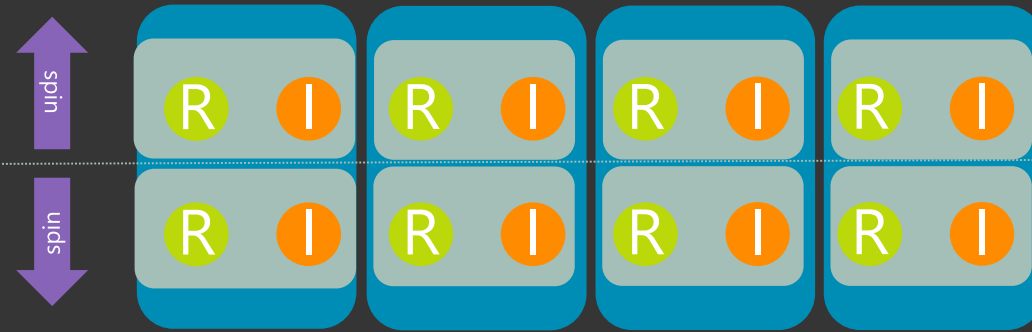
Insulator:



Electron

Pair

Normal S-Wave
Superconductor:



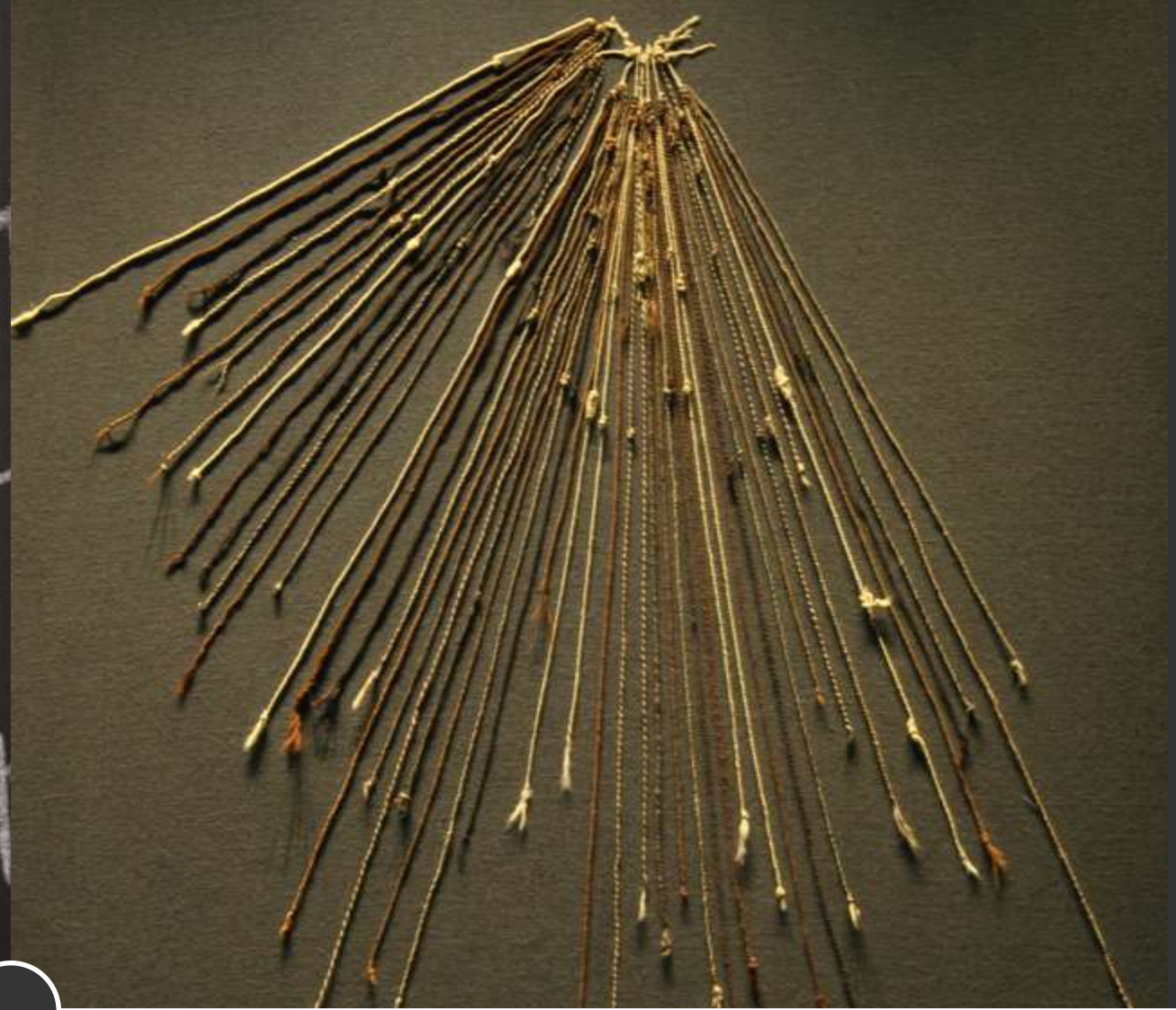
Topological
Superconductor:



Electron Fractionalization

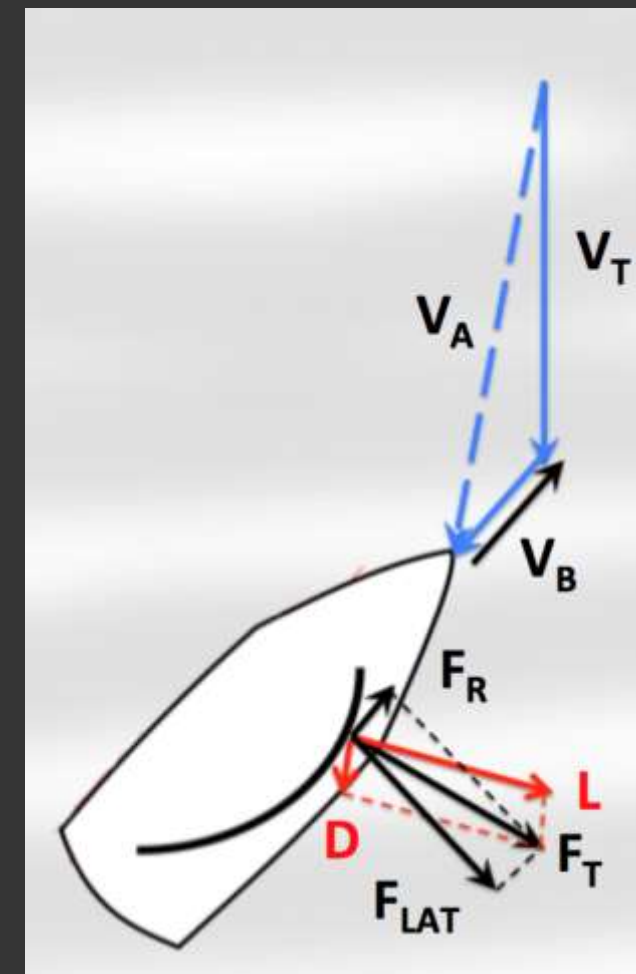
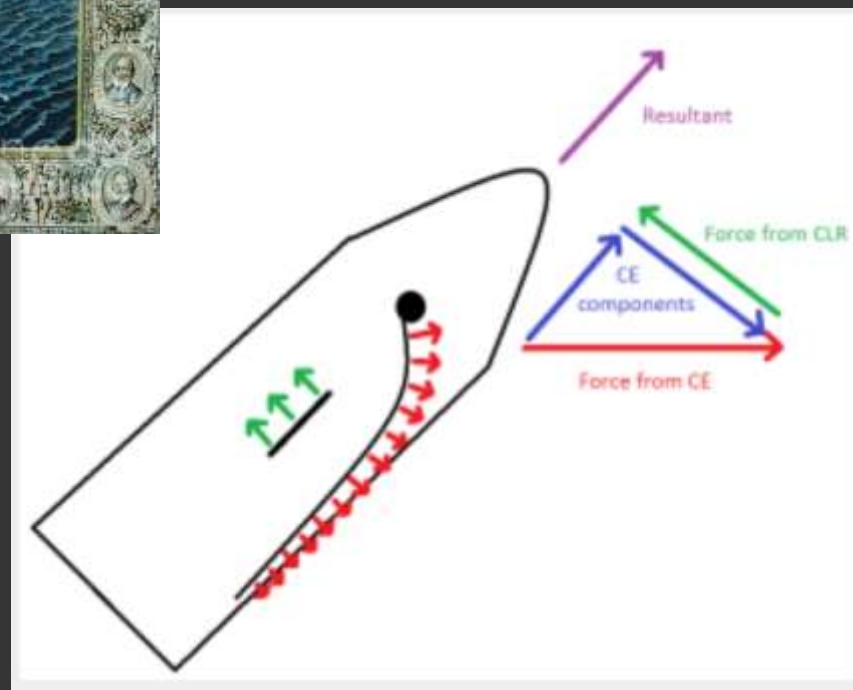


Superposition



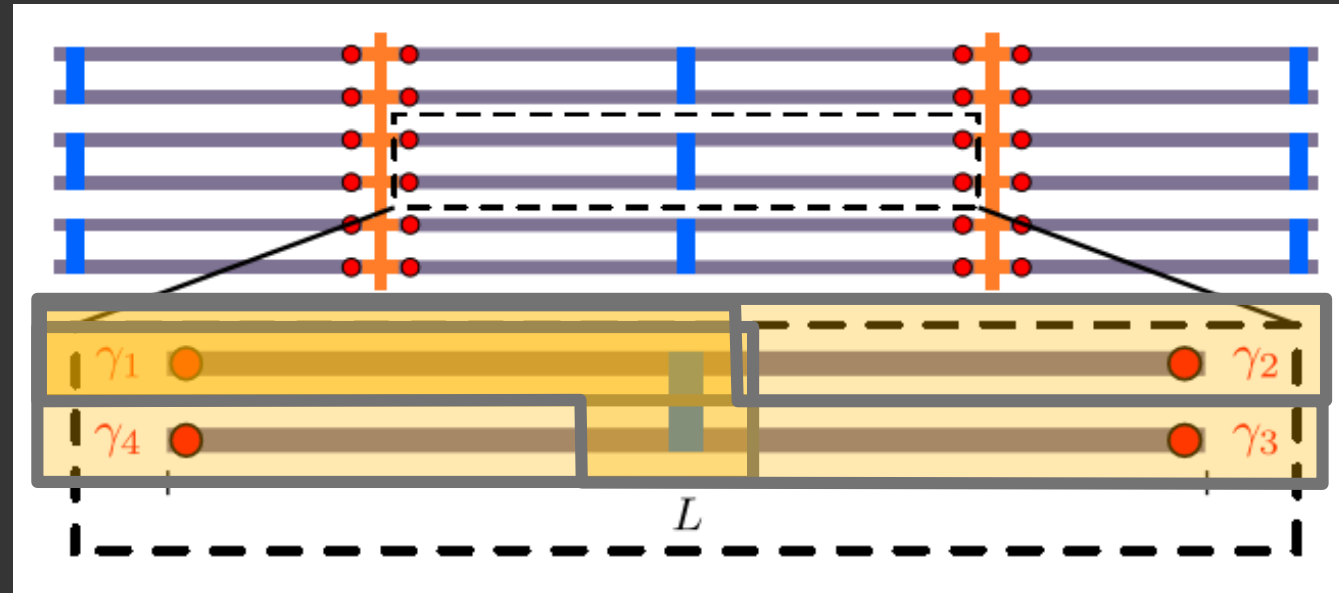
Inca Quipu

Sailing into the Wind



https://en.wikipedia.org/wiki/Forces_on_sails

Box Qubits: 1 Qubit Measurements



Measure two Horizontally = M_z

Measure two Vertically = M_x

Measure two Diagonally = M_y

Scalable Designs for Quasiparticle-Poisoning-Protected Topological Quantum Computation with Majorana Zero Modes

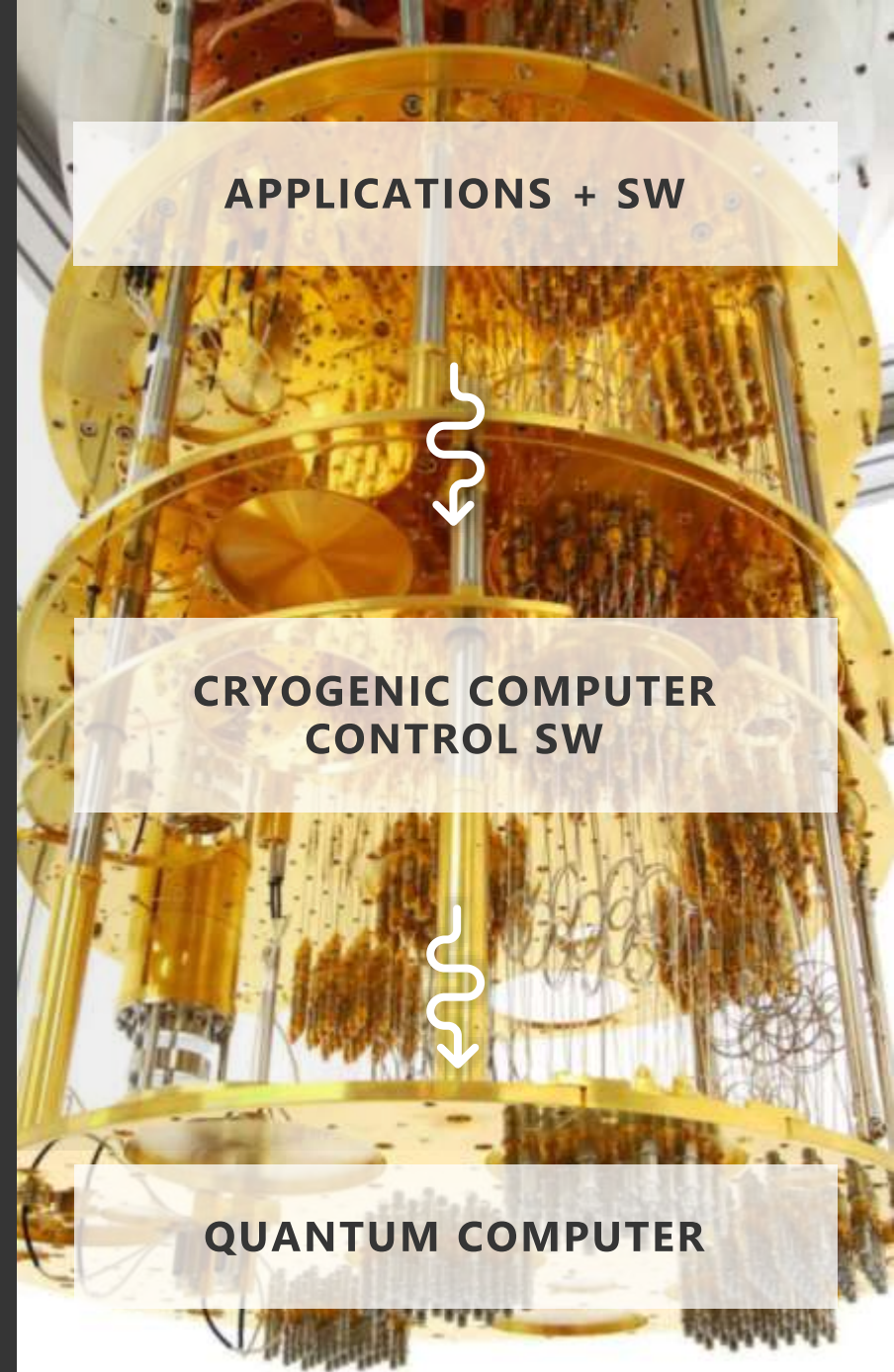
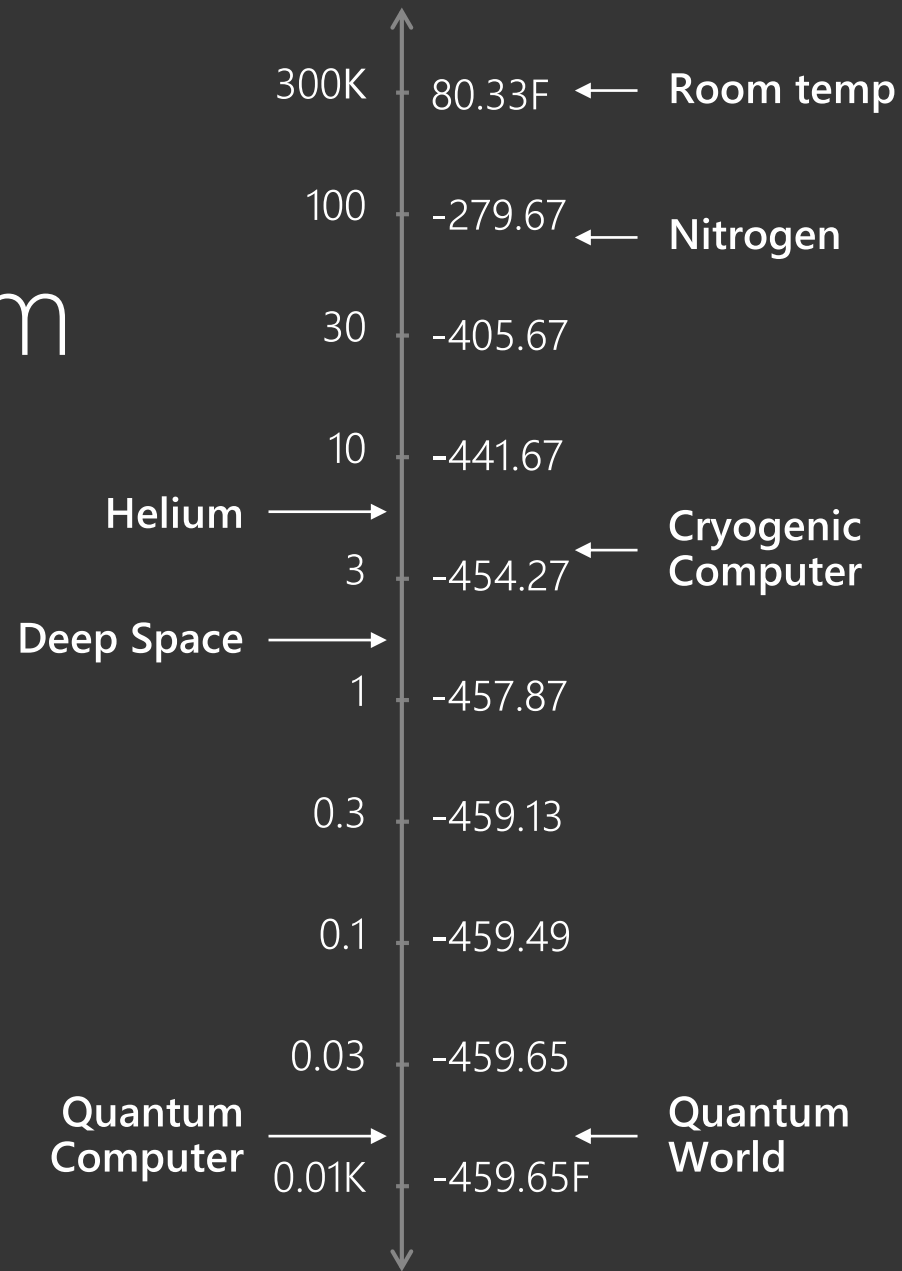
Torsten Karzig,¹ Christina Knapp,² Roman M. Lutchyn,¹ Parsa Bonderson,¹ Matthew Hastings,¹ Chetan Nayak,^{1,2} Jason Alicea,^{3,4} Karsten Flensberg,⁵ Stephan Plugge,^{5,6} Yuval Oreg,⁷ Charles Marcus,⁵ and Michael H. Freedman^{1,8}

Richard Feynman:
"Shut up & calculate!"

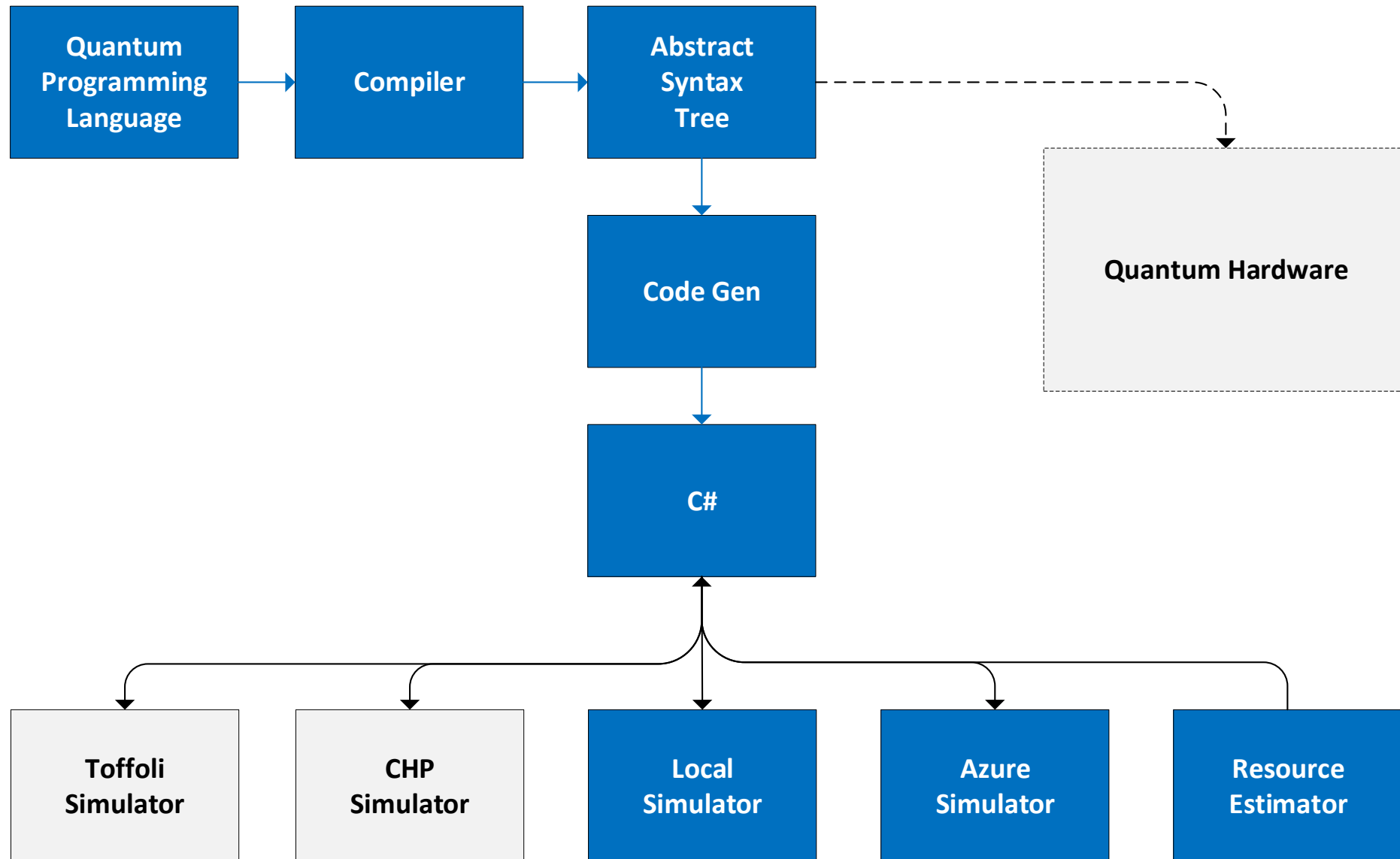
Quantum 2.0:
"Shut up & engineer!"



A complete, scalable, quantum system



Quantum development tools components



Quantum programming language

- Domain-specific language for quantum algorithms and development
 - Functional in flavor
 - Visual Studio integration
 - Quantum-specific features
 - Extensive libraries, samples, and documentation



Target machines

- **State-of-the-Art Local Simulator**
 - Simulate 30 qubits in 16 GB
 - Run locally on your PC
- **State-of-the-Art Azure Simulator**
 - Simulate more than 40 qubits
 - Run in Azure
- **Resource Estimator**
 - Determine resource costs of quantum program
 - Scale to large algorithms and numbers of qubits
- **Quantum Hardware**




```
1 operation () EPR (Qubit q1, Qubit q2) {
2     Body {
3         H (q1)
4         CNOT (q1,q2)
5     }
6 }
7
8 operation () Teleport (Qubit msg, Qubit here, Qubit there) {
9     Body {
10        EPR (here, there)
11        CNOT (msg, here)
12        H (msg)
13
14        let m_here = M (here)
15        if (m_here == One) {
16            X (there)
17        }
18
19        let m_msg = M (msg)
20        if (m_msg == One) {
21            Z (there)
22        }
23    }
24 }
25
26 operation (Result) TeleportTest (Result msg) {
27     Body {
28         mutable res = Zero
29         using (qubits = Qubit[3]) {
30             let msgQ = qubits[0]
31
32             // Set msgQ to message state
33             SetQubit (msg, msgQ)
34
35             Teleport (msgQ, qubits[1], qubits[2])
36
37             set res = M (qubits[2])
38         }
39         return res
40     }
41 }
```

112% < 2 authors, 2 changes | 1 work item

Output

Show output from: Source Control

Error List Output

Solution Explorer



Search Solution Explorer (Ctrl+;)

Solution 'HelloWorld-e2e' (1 project)

HelloWorld-e2e

Properties

References

HelloWorld.qb

HelloWorld.g.cs

HelloWorldDriver.cs

packages.config

Readme.md

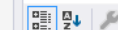
simulator.dll

Teleport.qb

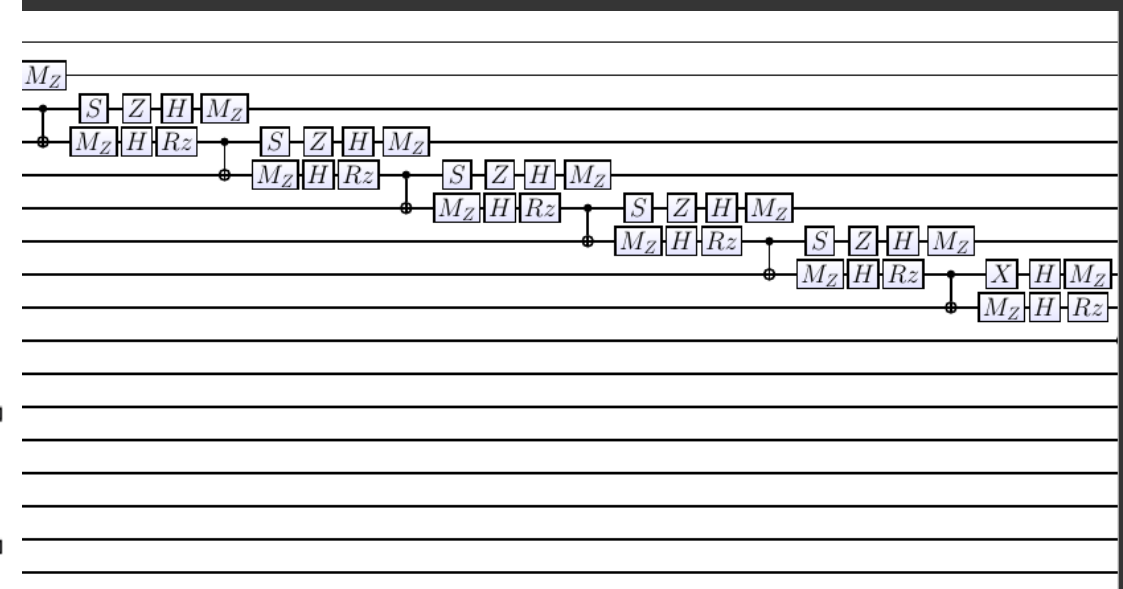
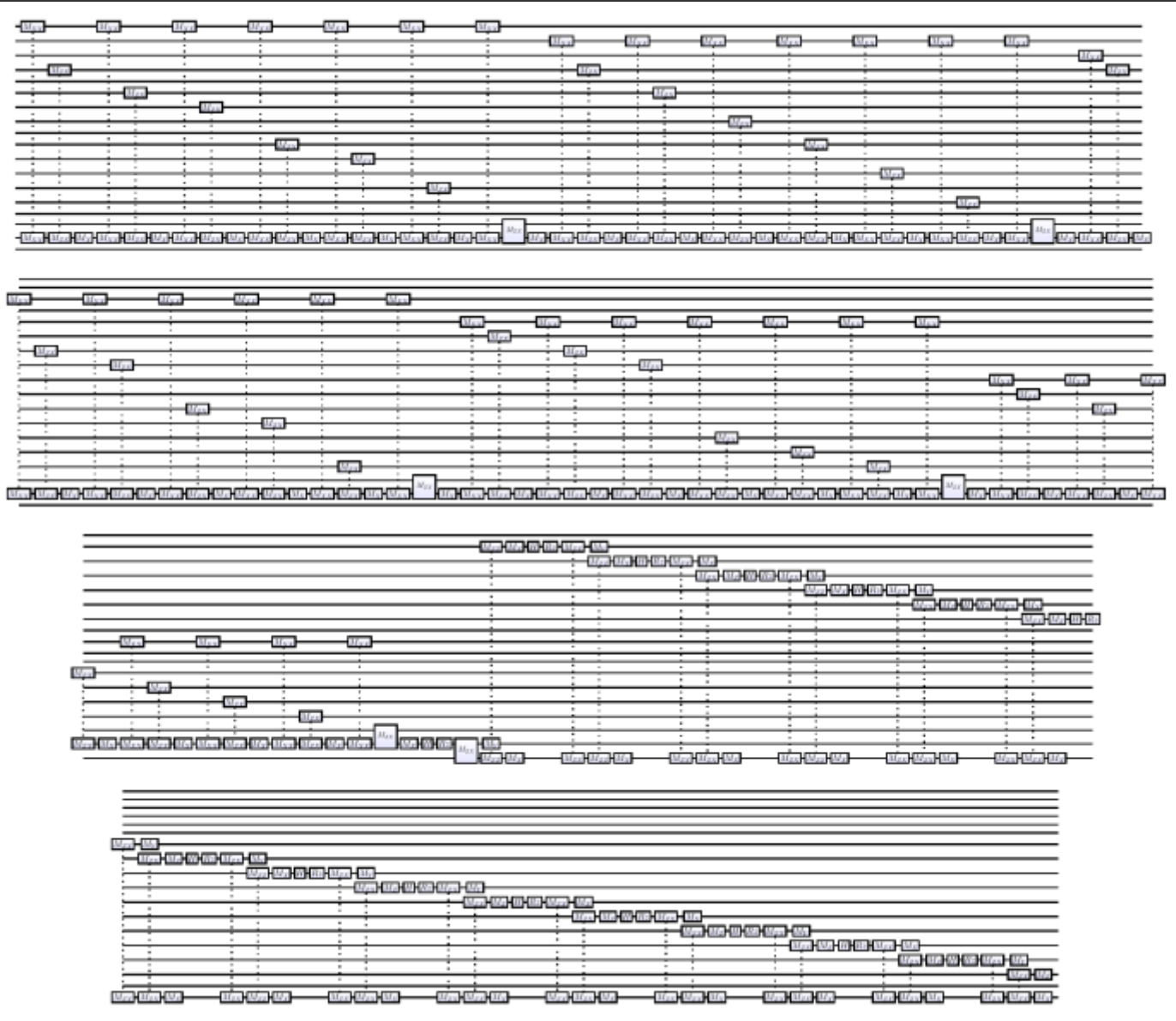
Teleport.g.cs

Solution Explorer Test Explorer Team Explorer

Properties



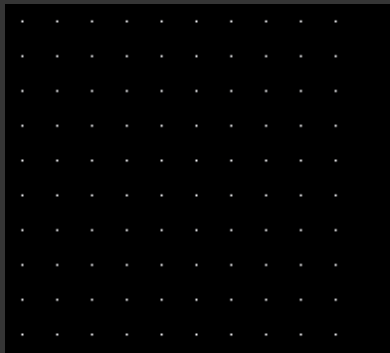
What about T gates?



Layout of T factory (DistillT)

DistillT: 1Q=65 2Q=100 LogQ=81 Frames=277

Connect	Dim	Data Rows	Phys Qubits	Data Teleport	Block Tele	Par Tele Depth
Rect	10x10	All	42	15/9	20/9	$4*(9+9)=72$
Rect	5x9	All	39	18/13	25/13	$4*(13+13)=104$
Rect	3x18	Half	39	40/31	40/31	$4*(31+31)=248$
Diag	3x9	Half	26	15/9	15/9	$4*(9+9)=72$
Diag	2x18	Half	34	39/24	36/24	$4*(24+24)=192$



Finding the ground state of Ferredoxin

Ferredoxin



Used in many metabolic reactions including energy transport in photosynthesis

Classical algorithm

!

INTRACTABLE

Quantum algorithm 2012

~24

BILLION YEARS

Quantum algorithm 2015

~1


HOUR

A photograph of a lush green cornfield in the foreground, with a sunset sky in shades of orange and yellow in the background. A small white contrail is visible in the upper left sky.


Nitrogen
fixation

A photograph of an industrial facility at sunset. A large plume of dark smoke or steam rises from a central chimney against the orange and yellow sky.

Carbon
capture

A photograph showing a close-up of blue solar panels in the foreground, with several high-voltage power line towers and transmission lines stretching into the distance under a blue sky.

Materials
science

A photograph of a person's hand in a light-colored sweater resting on the lid of a silver laptop. The laptop is open, and the background is a plain, light-colored surface.

Machine
learning



○
Climate
Change



○
Food
Production



○
Antibiotic
Resistance



Microsoft's Global Quantum Dream Team

microsoft.com/quantum



Backup Slides

Welcome to the
Quantum Age





Error Correction

Quantum Chemistry

$$H = \sum_{pq} h_{pq} a_p^\dagger a_q + \frac{1}{2} \sum_{pqrs} h_{pqrs} a_p^\dagger a_q^\dagger a_r a_s$$

Can quantum chemistry be performed on a small quantum computer:

Dave Wecker, Imp
Troyer H

As quantum c
with a small b
the near futur
computers ga
Feynman's ori
particular the
paper, we ana
standard algo
computer. We
ground state c
computers can
requires about
technology, th
coherently exe
that for quant
chemistry pro
<http://arxiv.org>

Ferredoxin (Fe_2S_2) used in many metabolic reactions including energy transport in photosynthesis

- *Intractable on a classical computer*
- *Assumed quantum scaling: ~24 billion years (N^{11} scaling)*
- *First paper: ~850 thousand years to solve (N^9 scaling)*
- *Second paper: ~30 years to solve (N^7 scaling)*
- *Third paper: ~5 days to solve ($N^{5.5}$ scaling)*
- *Fourth paper: ~1 hour to solve ($N^3, Z^{2.5}$ scaling)*

be
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Microsoft's unique approach



Revolutionary topological approach

Our [quantum approach](#) brings theory to reality, harnessing topological qubits that perform computations longer and more consistently, with fewer errors.



Bold investments and a global team

For more than a decade, we've made consistent investments and built the [quantum dream team](#) with collaboration across universities, industries, and more.



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Our [full-stack quantum-computing solution](#) is designed so you and your developers can approach quantum computing right away, with the ability to scale.



Building for Scale

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Sign up today:

Quantum programming language

Visual Studio extensions

Quantum simulator on Azure

