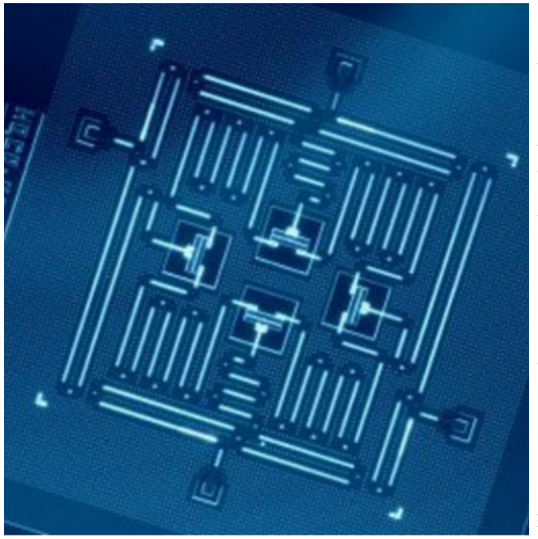


(*) IBM's quantum device. Source: Wikipedia (CC BY 4.0)

Como Programar Computadores Quânticos Reais

Franklin de Lima Marquezino
Universidade Federal do Rio de Janeiro
franklin@cos.ufrj.br

Setembro/2021

Objetivos desta apresentação

- **O que é a CQ?**

Trata-se de usar a mecânica quântica para resolver alguns problemas mais eficientemente

- **O que a CQ não é?**

Não é mágica! Ou seja, nem todo problema fica eficiente em computadores quânticos

- **O que temos hoje?**

Posso MESMO programar um computador quântico real?

- **O que teremos no futuro?**

Quais setores beneficiados no curto, médio e longo prazo

Os limites da computação clássica

- **Lei de Moore**

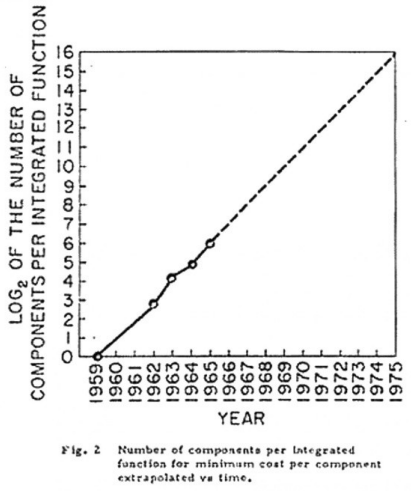
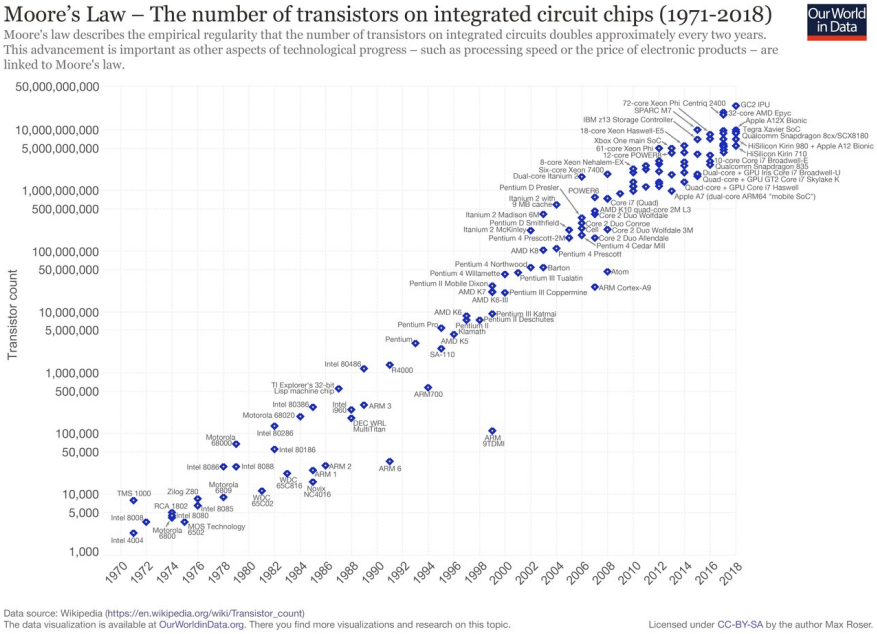
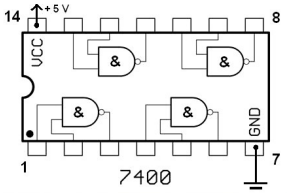


Fig. 2 Number of components per integrated function for minimum cost per component extrapolated vs time.

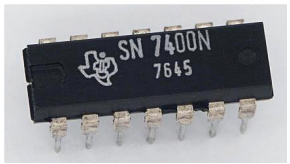
(*) Gordon Moore's original graph, Source: Electronics, 1965



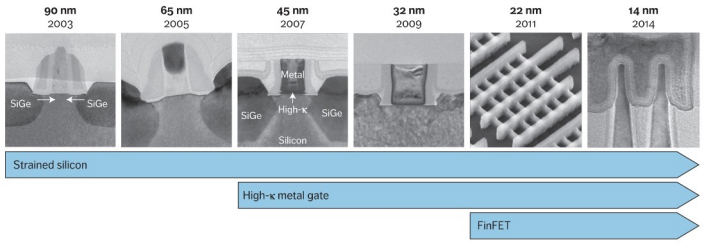
- **Miniaturização**



1960s



(*) Texas IC containing 4 NAND gates. Source: Wikipedia



(*) Source: IEEE Micro, www.computer

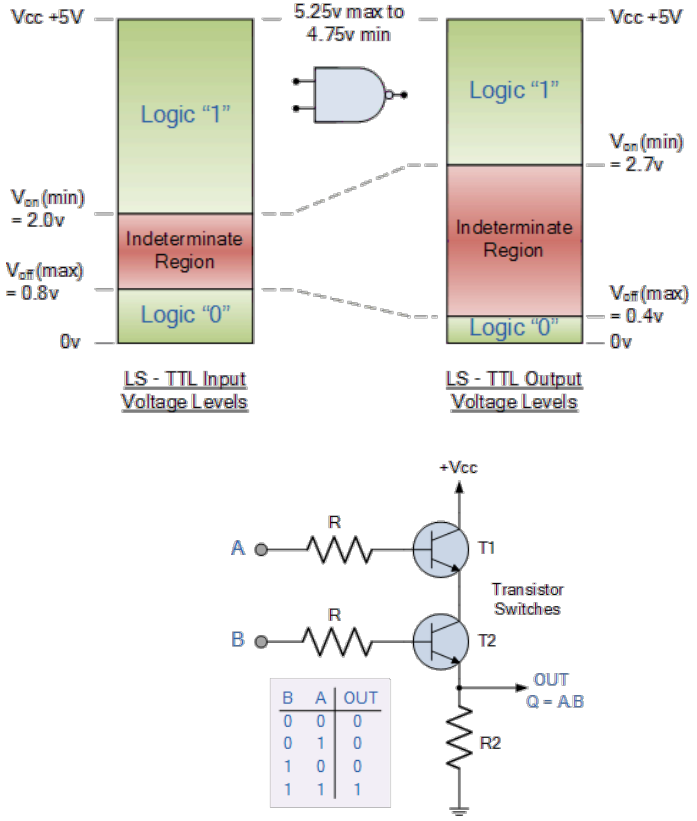
2015

Mecânica quântica

- **As regras do jogo, ou seja, os postulados da mecânica quântica**
  - Representação
  - Evolução
  - Medições
  - Composição
- **Conselho para estudantes:**
  Keep Calm
  and
  Learn Linear Algebra

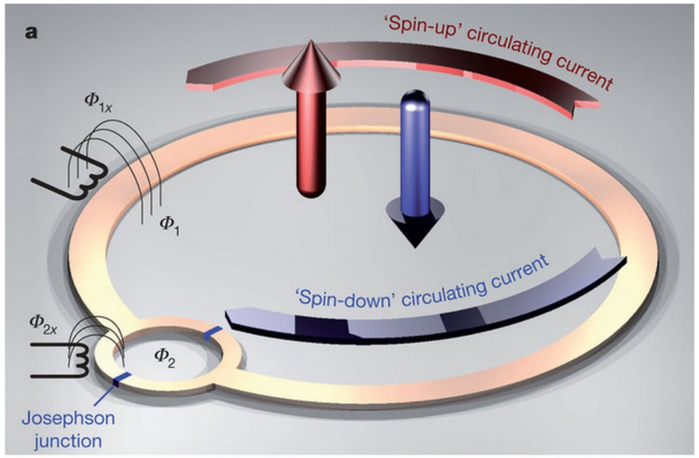
Apresentando os bits quânticos

- Bits (clássicos) podem ser 0 ou 1



(*) Source: www.eletronics-tutorials.ws

- Bits quânticos (qubits) pode ser um vetor (1,0) ou um vetor (0,1) ou qualquer combinação deles



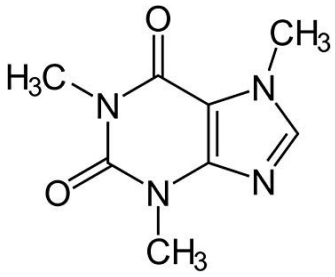
(*) Superconducting qubit. Source: "Quantum annealing with manufactured spins", Nature, 2011

Aplicações de computadores quânticos

- **Simulação**
  - Química quântica
  - Design de materiais
  - Design de fármacos
- **Otimização**
  - Finanças
  - Óleo & gás
- **Machine learning**
- **Buscas**
- **Fatoração**
- **etc.**

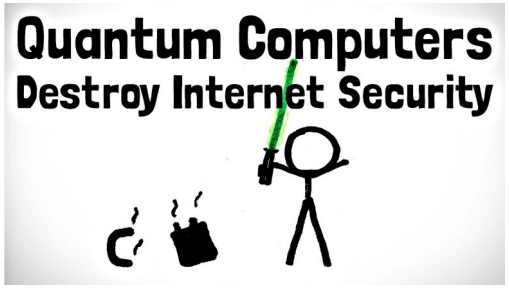
mais cedo

mais tarde



Simulação clássica, 10^{48} bits
(Mais que o número de átomos de nosso planeta!)

Simulação quântica, 160 qubits



(*) minutephysics, Youtube

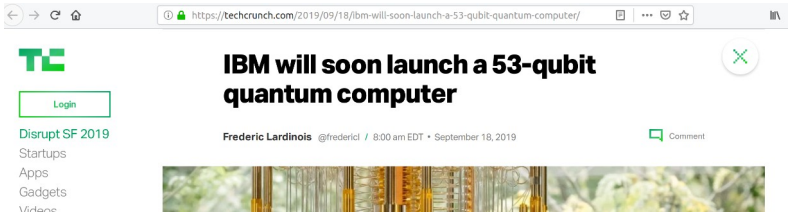
Requer muitos qubits e tolerância a falhas

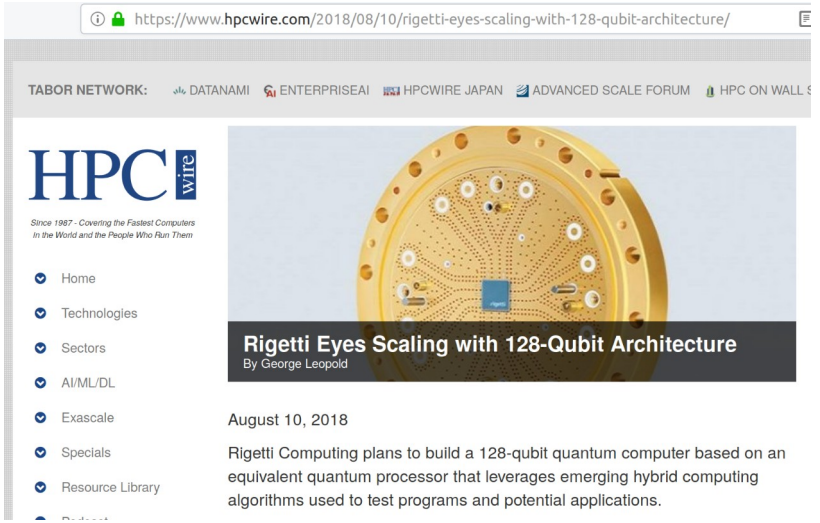
Supremacia quântica

- **Usar um computador quântico para resolver um problema que não seja “possível” em um computador clássico**
- **Não precisa ser problema útil**
- **Candidatos**
  - Fatoração
  - Amostragem de circuitos quânticos aleatórios
  - Amostragem de bosons

Supremacia quântica

- **Usar um computador quântico para resolver um problema que não seja "possível" em um computador clássico**
- **Não precisa ser problema útil**
- **Candidatos**
  - Fatoração
  - Amostragem de circuitos quânticos aleatórios
  - Amostragem de bosons
- **Supremacia quântica já foi demonstrada!** ***(Mesmo?)***
  - Simulações usando computadores clássicos só vão até 56 qubits até hoje
  - 9 PB para simular 50 qubits, cada qubit adicional dobra o requisito





Supremacia quântica

- Usar um computador quântico para resolver um problem computado
- Não precis
- Candidato
  - Fatoração
  - Amostrage
  - Amostrage
- Supremaci
  - Simulaçõe qubits até h
  - 9 PB para s requisito

Quantum technologies + Add to myFT

Google claims to have reached quantum supremacy

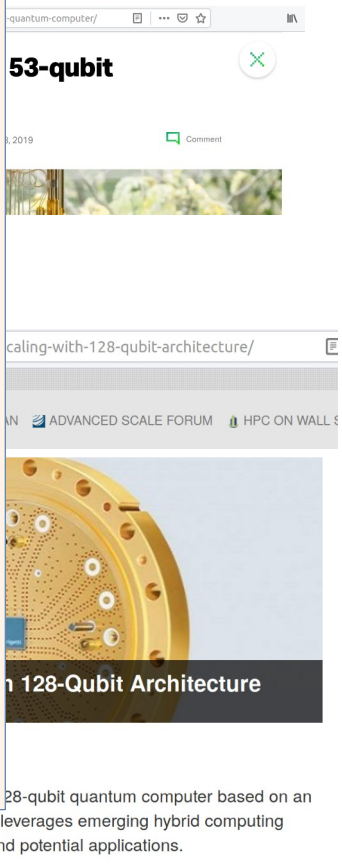
Researchers say their quantum computer has calculated an impossible problem for ordinary machines

Madhumita Murgia and **Richard Waters** SEPTEMBER 20 2019

0

Google claims to have built the first quantum computer that can carry out calculations beyond the ability of today's most powerful supercomputers, a landmark moment that has been hotly anticipated by researchers.

A paper by Google's researchers seen by the FT, that was briefly posted earlier this week on a Nasa website before being removed, claimed that their processor



Resource Library

28-qubit quantum computer based on an equivalent quantum processor that leverages emerging hybrid computing algorithms used to test programs and potential applications.

Supremacia quântica

nature

Article | Published: 23 October 2019

Quantum supremacy using a programmable superconducting processor

Frank Arute, Kunal Arya, [...] John M. Martinis

Nature **574**, 505–510(2019) | Cite this article

728k Accesses | **155** Citations | **6059** Altmetric | Metrics

d quantum

d an impossible problem for ordinary

0

mputer that can carry out calculations beyond the ability of today's most powerful supercomputers, a landmark moment that has been hotly anticipated by researchers.

A paper by Google's researchers seen by the FT, that was briefly posted earlier this week on a Nasa website before being removed, claimed that their processor

Resource Library

53-qubit

caling-with-128-qubit-architecture/

ADVANCED SCALE FORUM | HPC ON WALL

n 128-Qubit Architecture

28-qubit quantum computer based on an equivalent quantum processor that leverages emerging hybrid computing algorithms used to test programs and potential applications.

- Supremac
  - Simulações
    qubits até h
  - 9 PB para s
    requisito

Supremacia quântica

nature

Article | Published: 23 October 2019

Quant
progra
proces

Frank Arute, I

Nature **574,**

728k Access

Suprem

- Simula
  qubits até h
- 9 PB para s
  requisito

THE DAILY NEWSLETTER
Sign up to our daily email newsletter

NewScientist

News Podcasts Video Technology Space Physics Health More Shop Tours Events

It's official: Google has achieved quantum supremacy

PHYSICS 23 October 2019

By Daniel Cossins

A paper by Google's researchers seen by the FT, that was briefly posted earlier this week on a Nasa website before being removed, claimed that their processor

28-qubit quantum computer based on an equivalent quantum processor that leverages emerging hybrid computing algorithms used to test programs and potential applications.

Resource Library

Supremacia quântica

nature

Article | Published: 23 October 2019

Quant
progra
proces

Frank Arute, I

Nature **574,**

728k Access

Suprem

- Simula
qubits até h
- 9 PB para s
requisito

THE DAILY NEWSLETTER
Sign up to our daily email newsletter

News Podcasts Video Technolog

It's official: Go
quantum supr

PHYSICS 23 October 2019

By Daniel Cossins

A paper by Google's research
this week on a Nasa website

The New York Times

Opinion

Why Google's Quantum Supremacy Milestone Matters

The company says its quantum computer can complete a calculation much faster than a supercomputer. What does that mean?

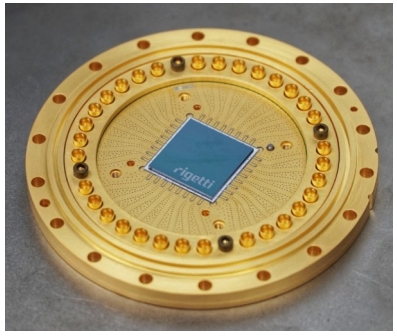
By Scott Aaronson

Dr. Aaronson is the founding director of the Quantum Information Center at the University of Texas at Austin.

Oct. 30, 2019

Computadores quânticos atuais

- **Para rodar um programa quântico, você vai precisar de um computador quântico!**
- **Já existem alguns computadores QREI disponíveis (poucos qubits, ruidosos)**
  - IBM Q Experience
  - Rigetti (precisa de convite)
  - Dwave Leap (não no Brasil)
  - Xanadu Cloud (precisa de convite)
- **Vários outros já foram anunciados**



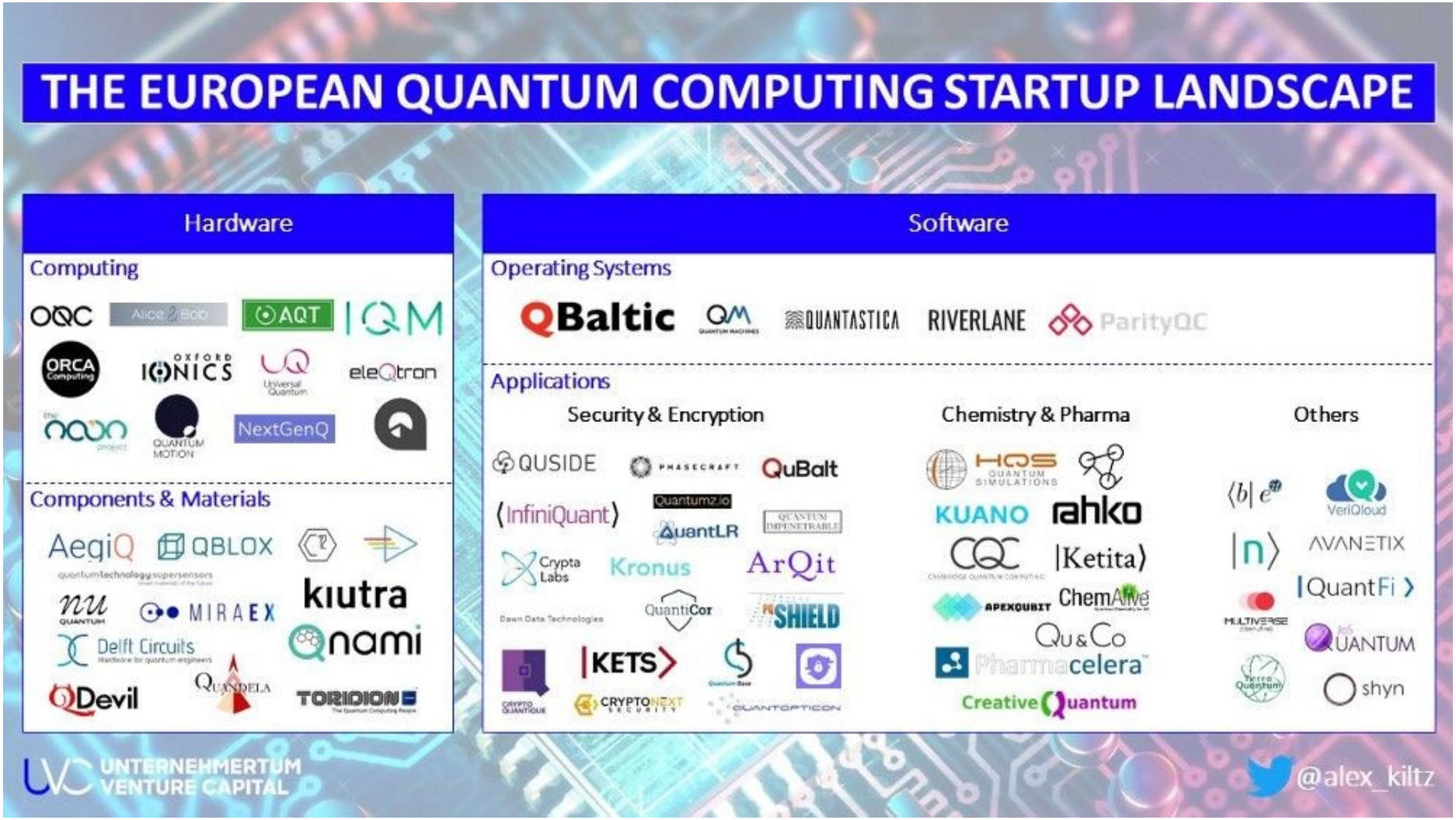
Empresas

Software e consultoria

Hardware quântico

. . . e muitas outras

Empresas

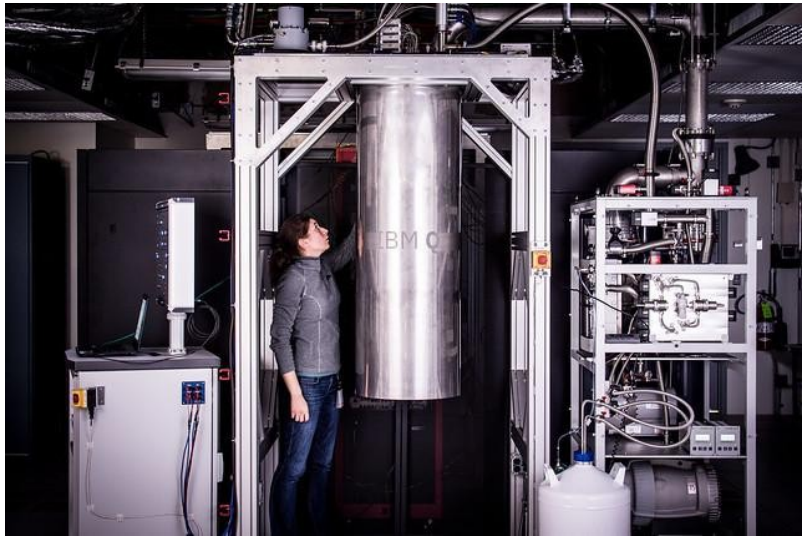

THE EUROPEAN QUANTUM COMPUTING STARTUP LANDSCAPE
Hardware
Computing
OQC
Alice & Bob
AQT
IQM
ORCA Computing
OXFORD IONICS
Universal Quantum
eleQtron
the nQan project
QUANTUM MOTION
NextGenQ
Components & Materials
AegiQ
QBLOX
quantumtechnology supersensors
nu QUANTUM
MIRAEX
kiutra
Delft Circuits
Hardware for quantum engineers
Qnami
QDevil
QUANDELA
TORIDION
The Quantum Computing People
Software
Operating Systems
QBaltic
QM
QUANTUM MACHINES
QUANTASTICA
RIVERLANE
ParityQC
Applications
Security & Encryption
QUSIDE
PHASECRAFT
QuBalt
InfiniQuant
Quantumz.io
QuantLR
QUANTUM IMPENETRABLE
Crypta Labs
Kronus
ArQit
Dawn Data Technologies
QuantiCor
SHIELD
CRYPTO QUANTIQUE
KETS
CRYPTONEXT SECURITY
Quantum Base
QUANTOPTICON
Chemistry & Pharma
HQS QUANTUM SIMULATIONS
KUANO
rahko
CQC
CAMBRIDGE QUANTUM COMPUTING
Ketita
APEXQUBIT
ChemAlive
Qu&Co
Pharmacelera
Creative Quantum
Others
VeriQloud
AVANETIX
QuantFi
MULTIVERSE
QUANTUM
Terra Quantum
shyn
UNTERNEHMERTUM VENTURE CAPITAL
@alex_kiltz

Programando um computador quântico

- IBM: circuit composer, Qasm, Qiskit (Python)
- Rigetti: Forest (Python)
- Xanadu: PennyLane (Python)
- Dwave: Ocean (Python)
- Microsoft: Q#
- Outros: ProjectQ, Qubiter, etc

IBM Quantum Experience

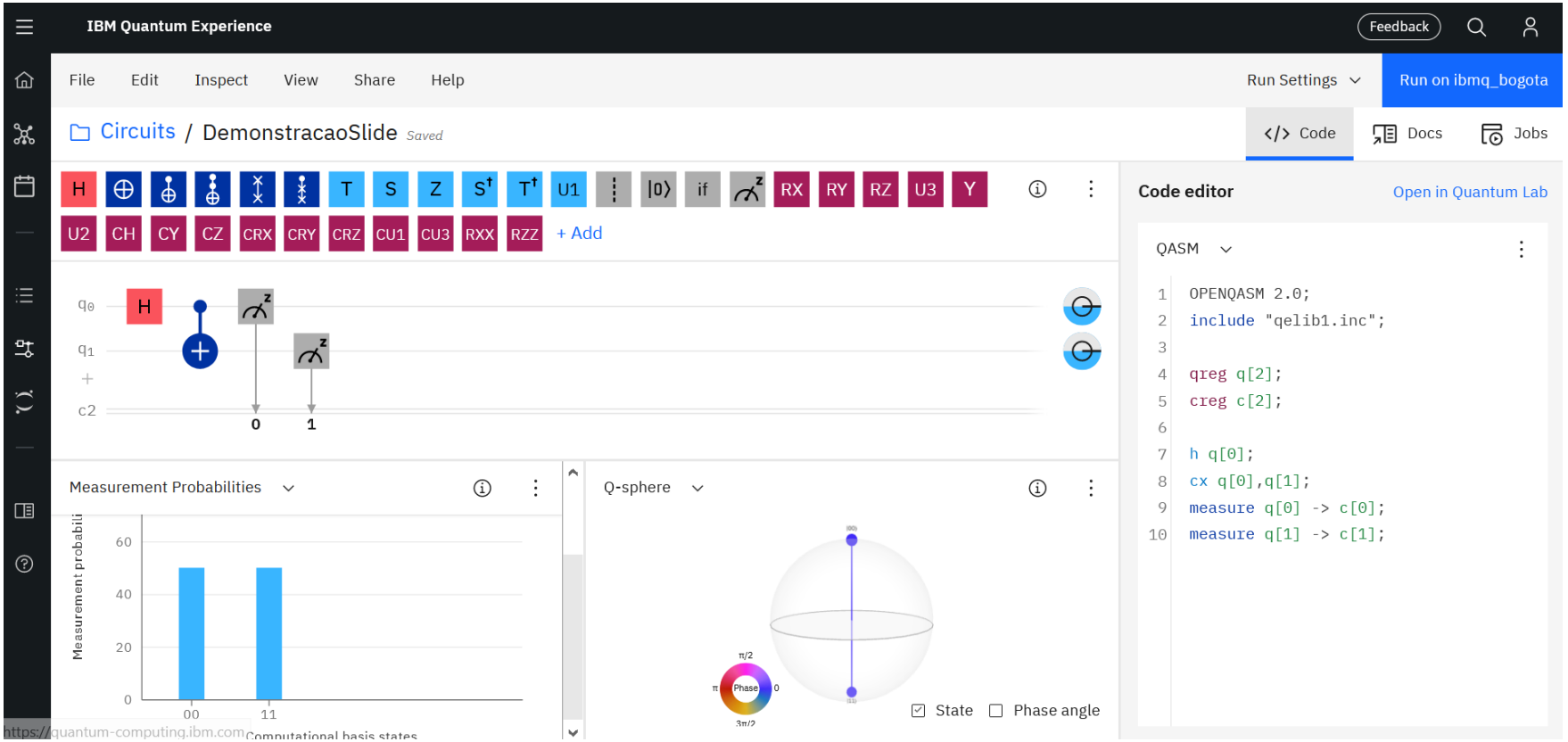
- **Boa oportunidade para experimentar computadores QREI**
- **Sistemas premium**
  - IBM Q Tokyo (20 qubits)
- **Sistemas públicos**
  - IBM Q Melbourne (14 qubits)
  - IBM Q Ourense, Vigo etc (5 qubits)
  - IBM QASM Simulator (até 32 qubits simulados)



(*) IBM Research

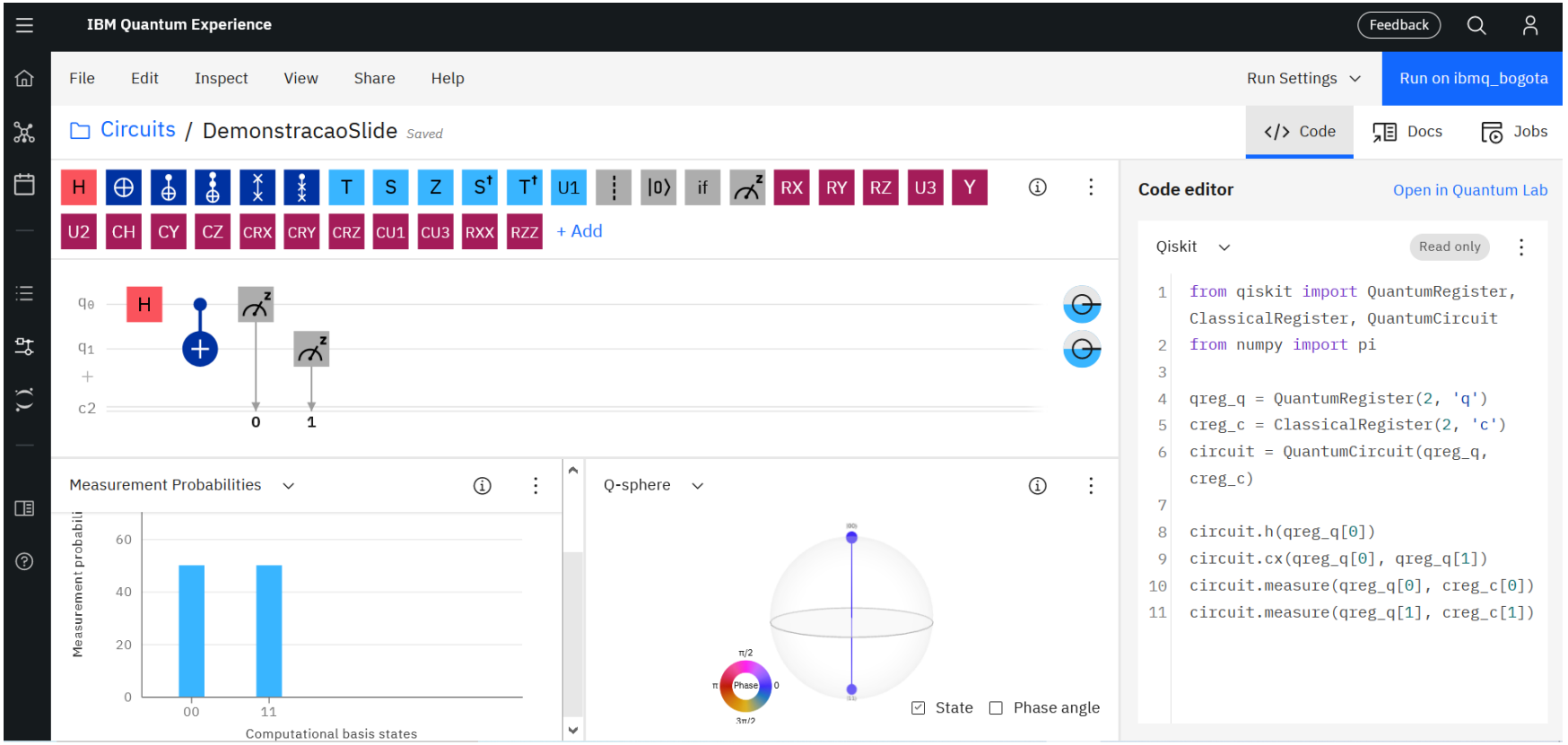
Como programar o IBM Q

- Comece online!
- Vá até https://quantum-computing.ibm.com
- Comece pelo Circuit Composer



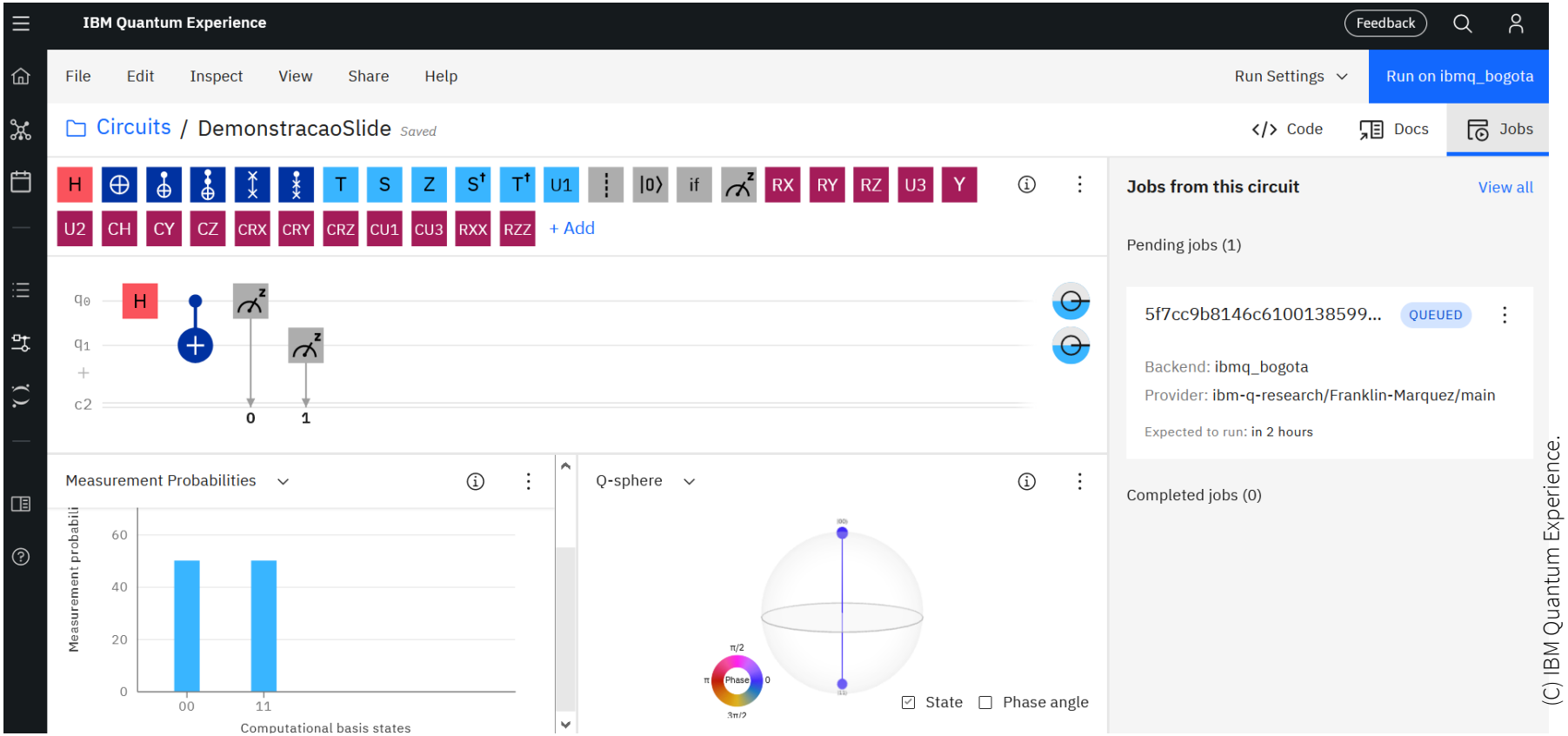
Como programar o IBM Q

- O código é gerado automaticamente em QASM e em Python (Qiskit)



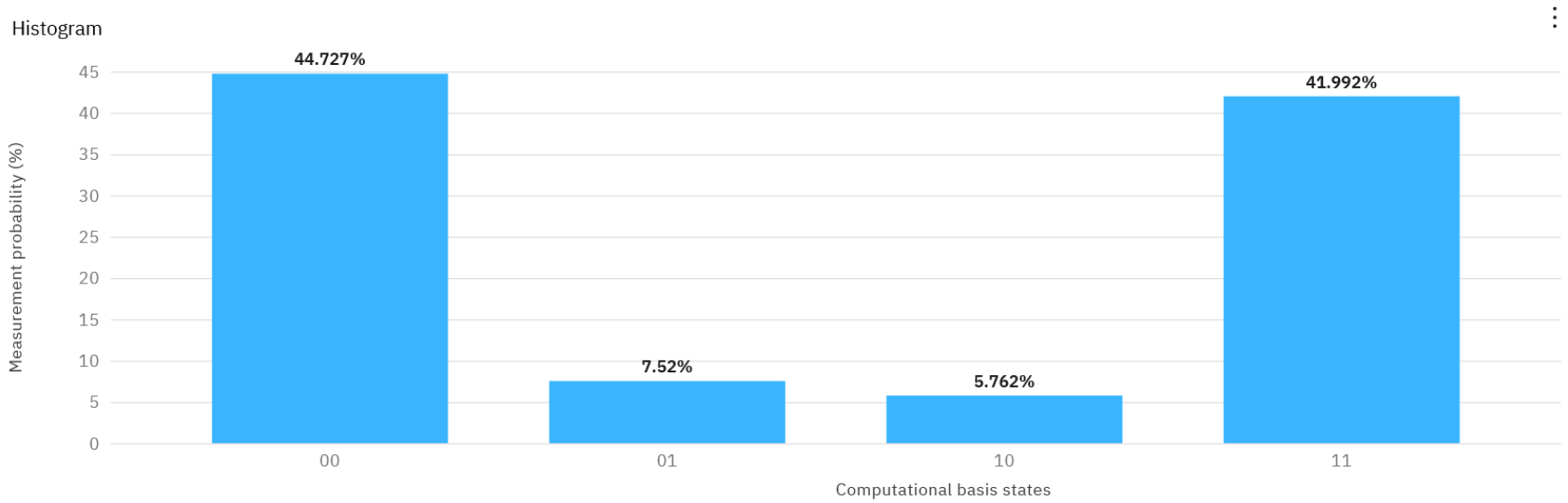
Como programar o IBM Q

- Jobs submetidos para o computador quântico real podem demorar! Também é possível simular



Como ler os resultados

Result



Mapa de acoplamentos

online

ibmq_santiago (5 qubits, QV32)

Queue: 34 jobs

online

ibmq_bogota (5 qubits, QV32)

Queue: 14 jobs

Reservable

online

ibmq_rome (5 qubits, QV32)

Queue: 32 jobs

1 upcoming reservations

ibmq_bogota v1.0.4

online

Queue: 14 jobs

Reservable

Providers with access:

ibm-q-research/Franklin-Marquez /main

Qubits ⇅ Connectivity

Single-qubit U2 error rate

1.633e-4 6.264e-4

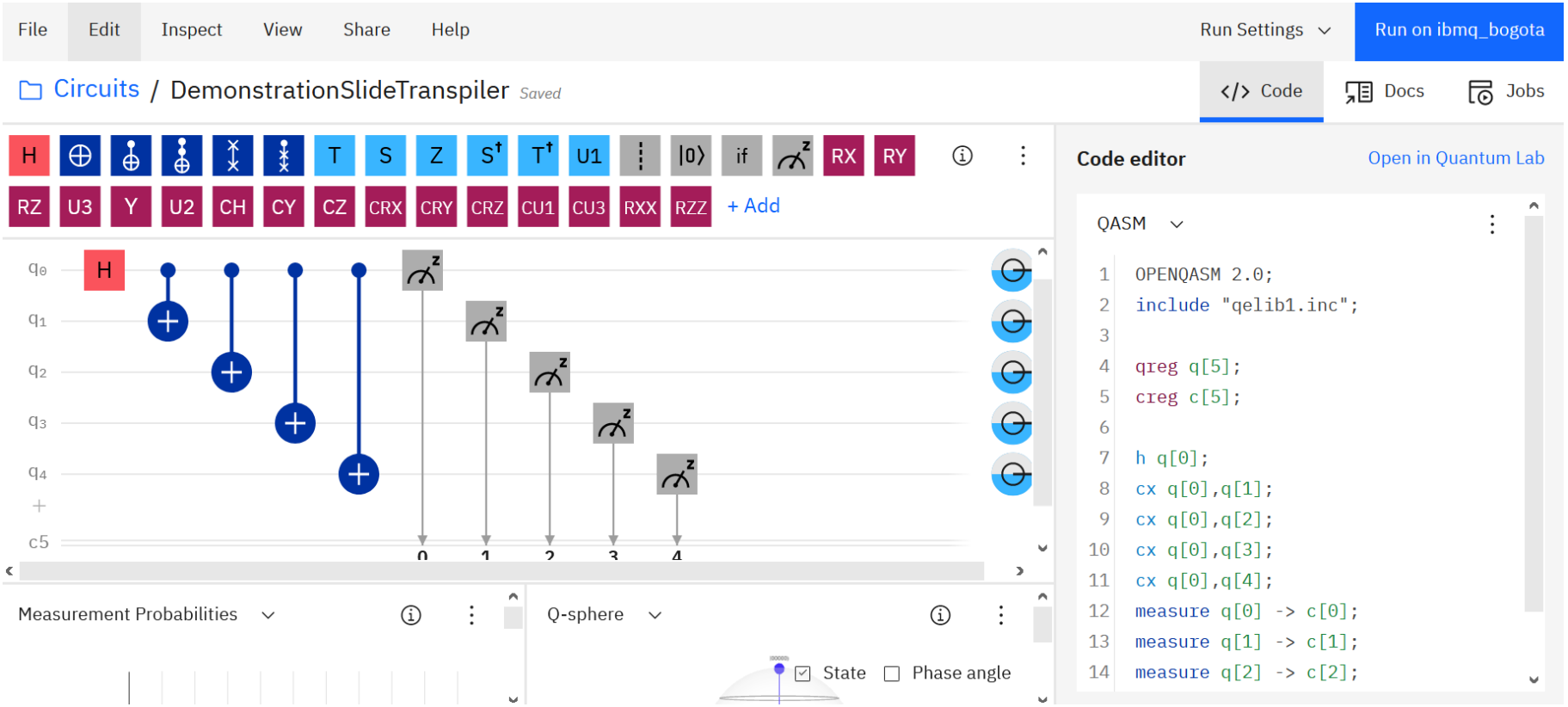
CNOT error rate

9.249e-3 4.606e-2

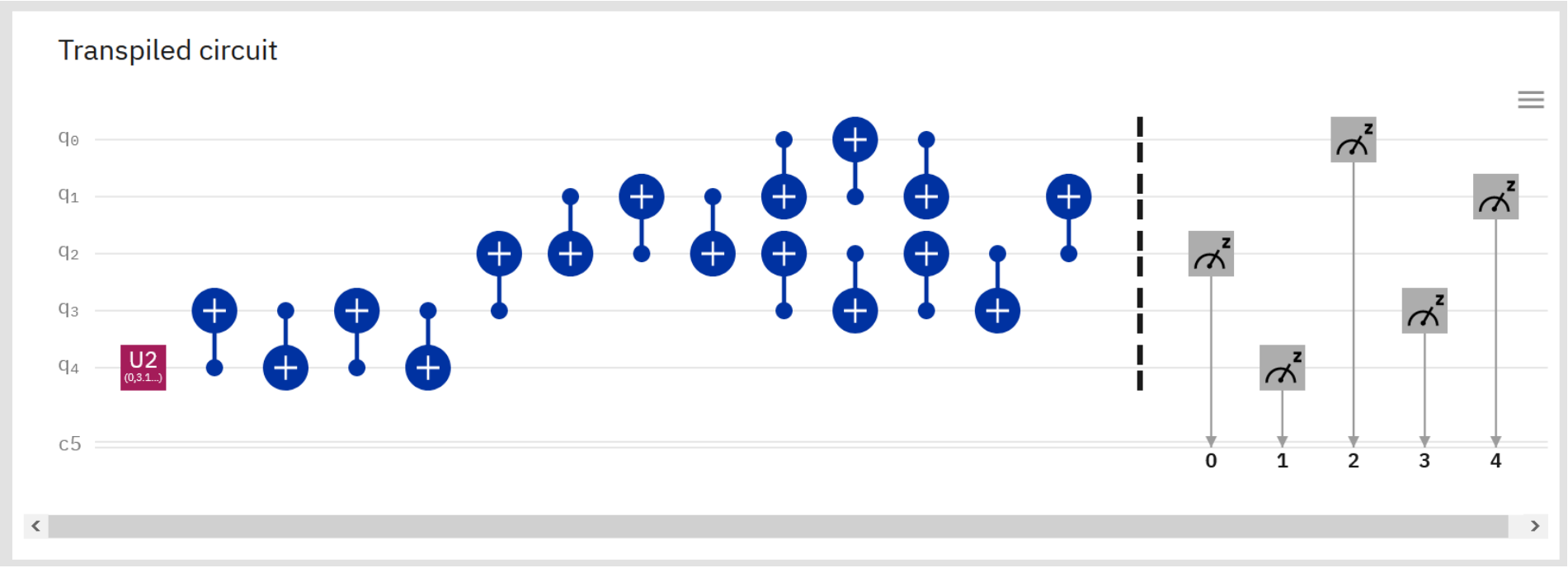
Download Calibrations

Qubits 5	Quantum Volume 32
Online since Jun 03, 2020	Basis gates u1, u2, u3, cx, id
Maximum shots 8192	Maximum circuits 900

Programando em alto nível

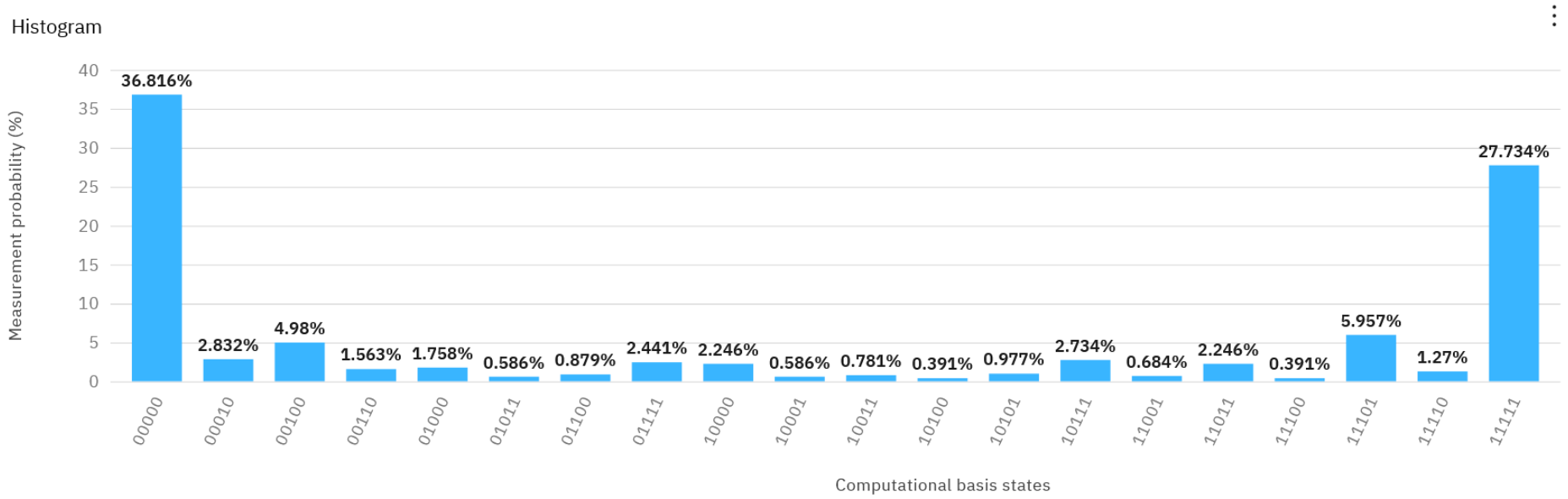


Transpilação



Resultado obtido pelo circuito transpilado

Result



Executando no Quantum Lab (Notebook)

IBM Quantum Experience

Feedback

File Edit View Insert Cell Kernel Widgets Help

Trusted Python 3

jupyter

Run Code

In [7]:

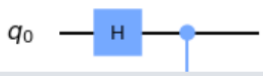
```
qreg_q = QuantumRegister(2, 'q')
creg_c = ClassicalRegister(2, 'c')
circuit = QuantumCircuit(qreg_q, creg_c)

circuit.h(qreg_q[0])
circuit.cx(qreg_q[0], qreg_q[1])
```

```
<qiskit.circuit.instructionset.InstructionSet at 0x7f24414ec550>
```

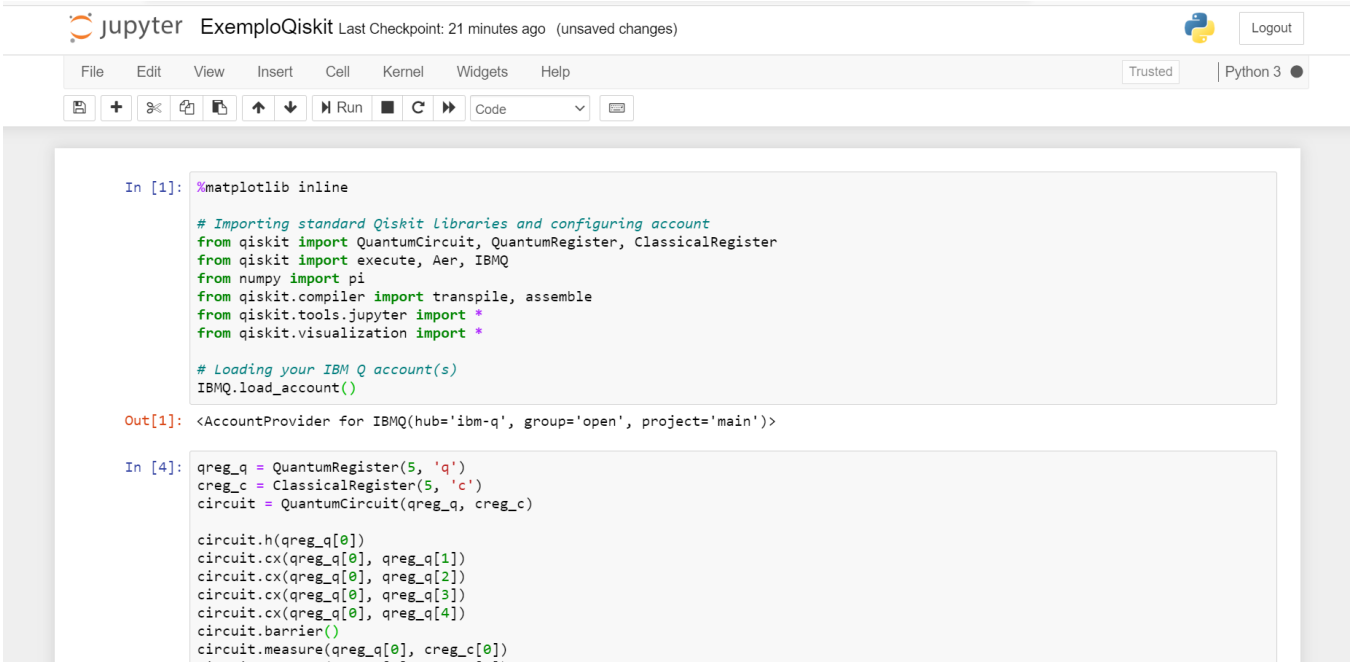
In [8]:

```
circuit.draw('mpl')
```



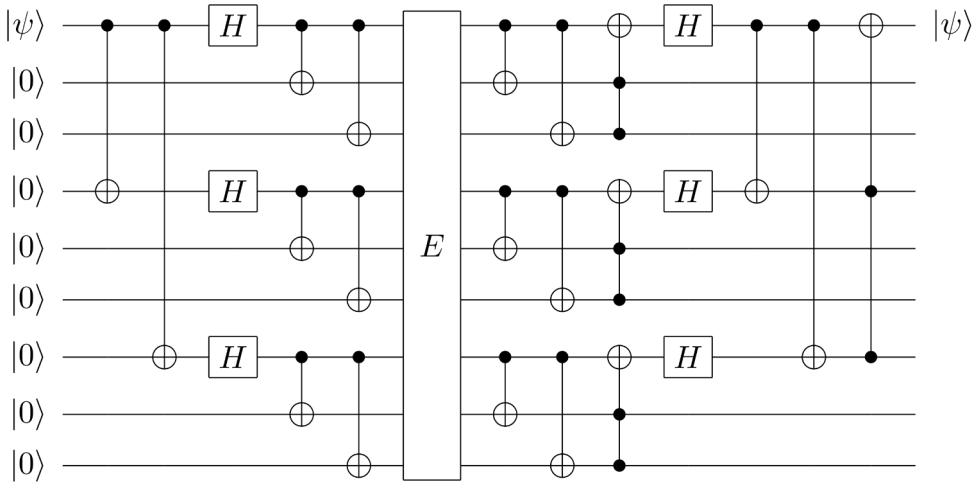
Executando localmente

- Necessário Python 3
- Recomendável Jupyter Notebook
- Baixe o qiskit em https://qiskit.org ou via pip install qiskit
- Recomendável pip install qiskit[visualization]



Correção de erros quânticos

- É possível corrigir erros
- Nós *devemos* corrigir erros de computadores quânticos
- Entretanto, é caro (requer muitos qubits)
- Taxa de erros precisa estar abaixo de um limiar



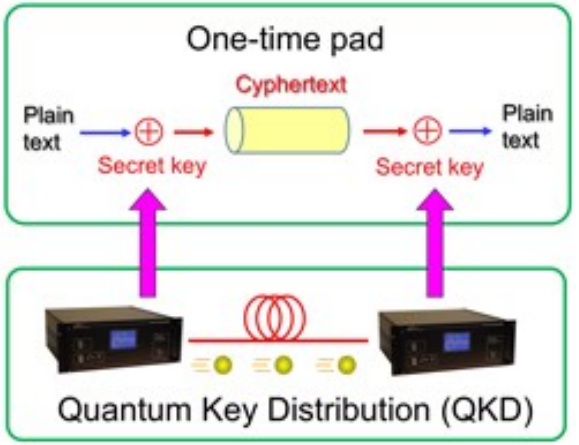
(*) Shor code: 1 logical qubit is mapped to 9 physical qubits.
Source: Wikipedia.

Algoritmos importantes

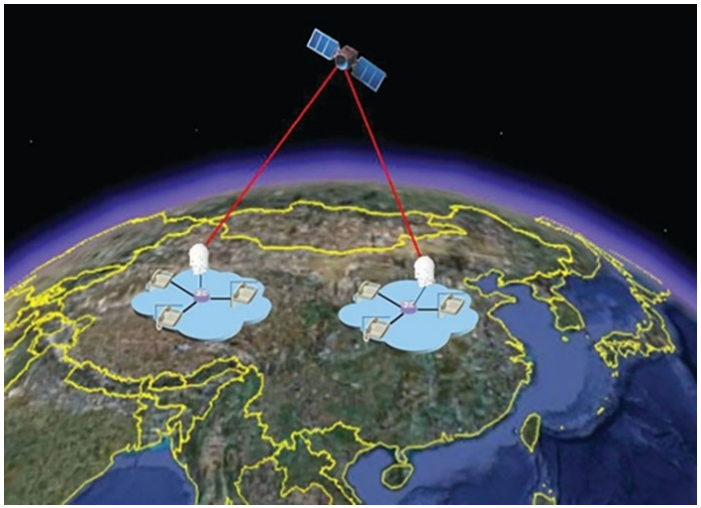
- **Algoritmos**
  - Shor (1994)
  - Grover (1996)
  - Element distinctness (2004)
  - HHL (2009)
- **Técnicas**
  - HSP
  - Amplitude amplification
  - Quantum walks
  - QAOA
  - Quantum annealing
- **Para uma lista completa veja http://quantumalgorithmzoo.org/**

Consequências para criptografia

- CQ quebra RSA
  (mas requer muitos qubits)
- Motiva a criptografia
  pós-quântica
- Novas oportunidades para troca de
  chaves e comunicação segura



(*) Source: www.nict.go.jp



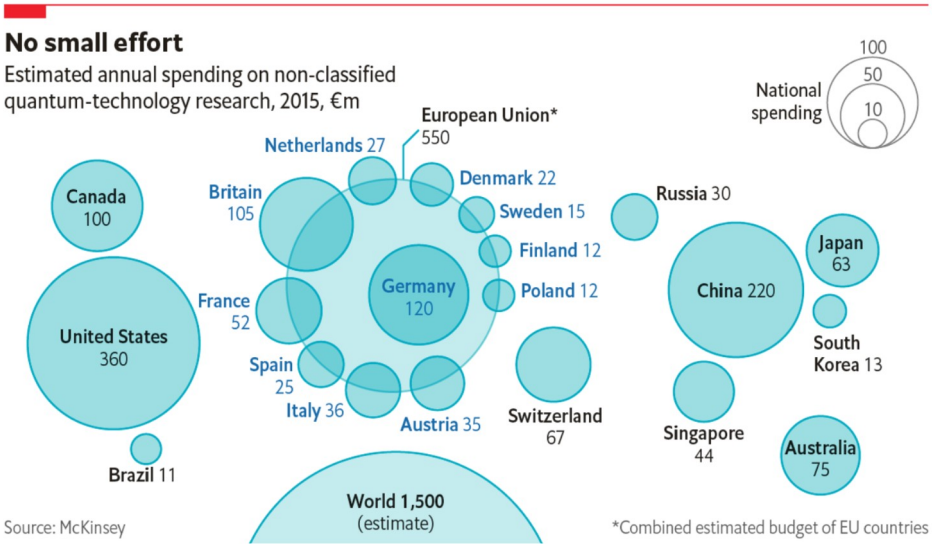
(*) Source: physicsworld.com

Como se preparar nessa área

- Graduação: matemática, computação, engenharia, física etc (várias possibilidades)
- Muita atenção aos cursos de Álgebra Linear
- Aprenda a programar os computadores quânticos da IBM (github programaquantica)
- Iniciação científica, se possível, é interessante!
- Mestrado/Doutorado

Conclusão

- Supremacia quântica: demonstrada (mesmo?)
- QREI / Impacto limitado em negócios: próximos 5-10 anos
- Correção de erros / Impacto mais amplo: 10-20 anos
- Tolerância a falhas / Escala completa: 20+ anos
- Fiquem atentos! Muitas oportunidades na academia e na indústria



The New York Times

The Next Tech Talent Shortage: Quantum Computing Researchers

By Cade Metz

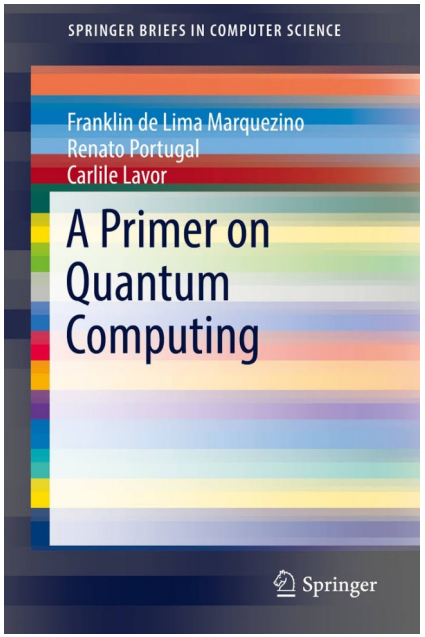
Oct. 21, 2018

Christopher Savoie, founder and chief executive of a start-up called Zapata, offered jobs this year to three scientists who specialize in an increasingly important technology called quantum computing. They accepted.

Several months later, the Cambridge, Mass., company was still waiting for the State

Para saber mais

- Apostila
  github.com/programaquantica
- Livro
  www.springer.com/gp/book/9783030190651
- Seminário PESC
  www.youtube.com/watch?v=MXovwCMx3uA%22



Obrigado!

Computação Quântica

Franklin de Lima Marquezino
Universidade Federal do Rio de Janeiro
franklin@cos.ufrj.br