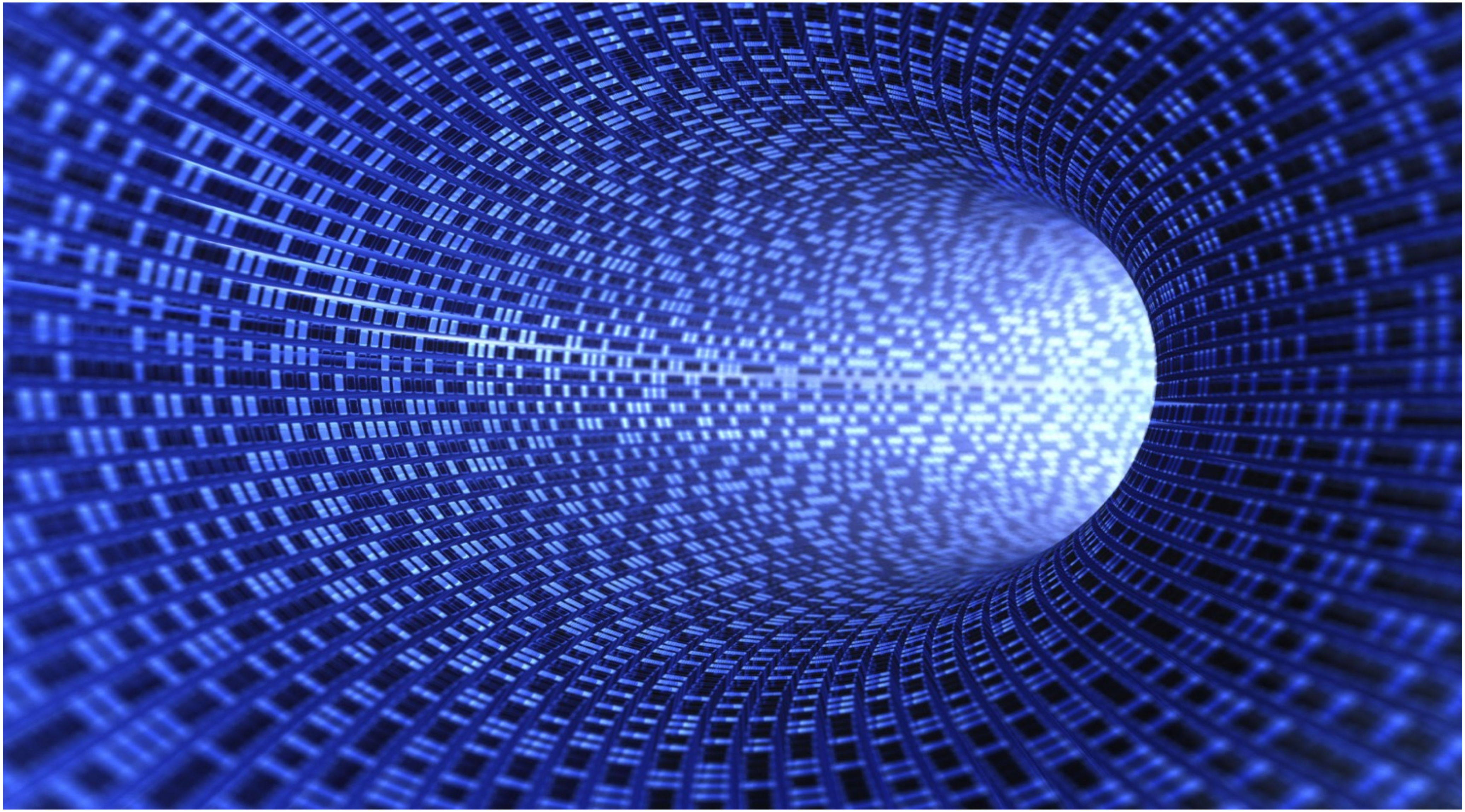
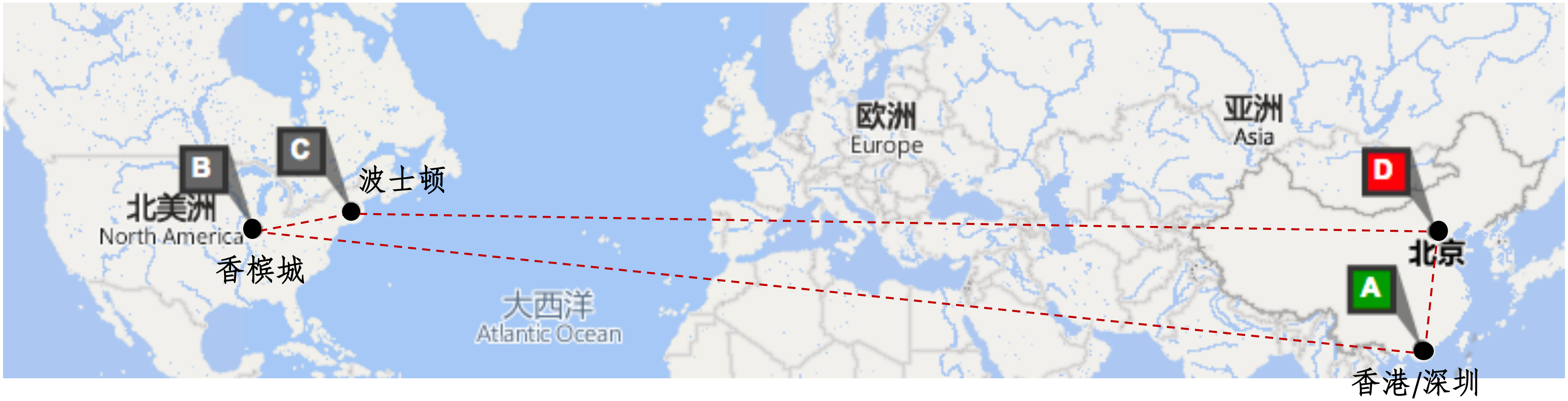


量子计算的机遇

翁文康
南方科技大学
物理系副教授



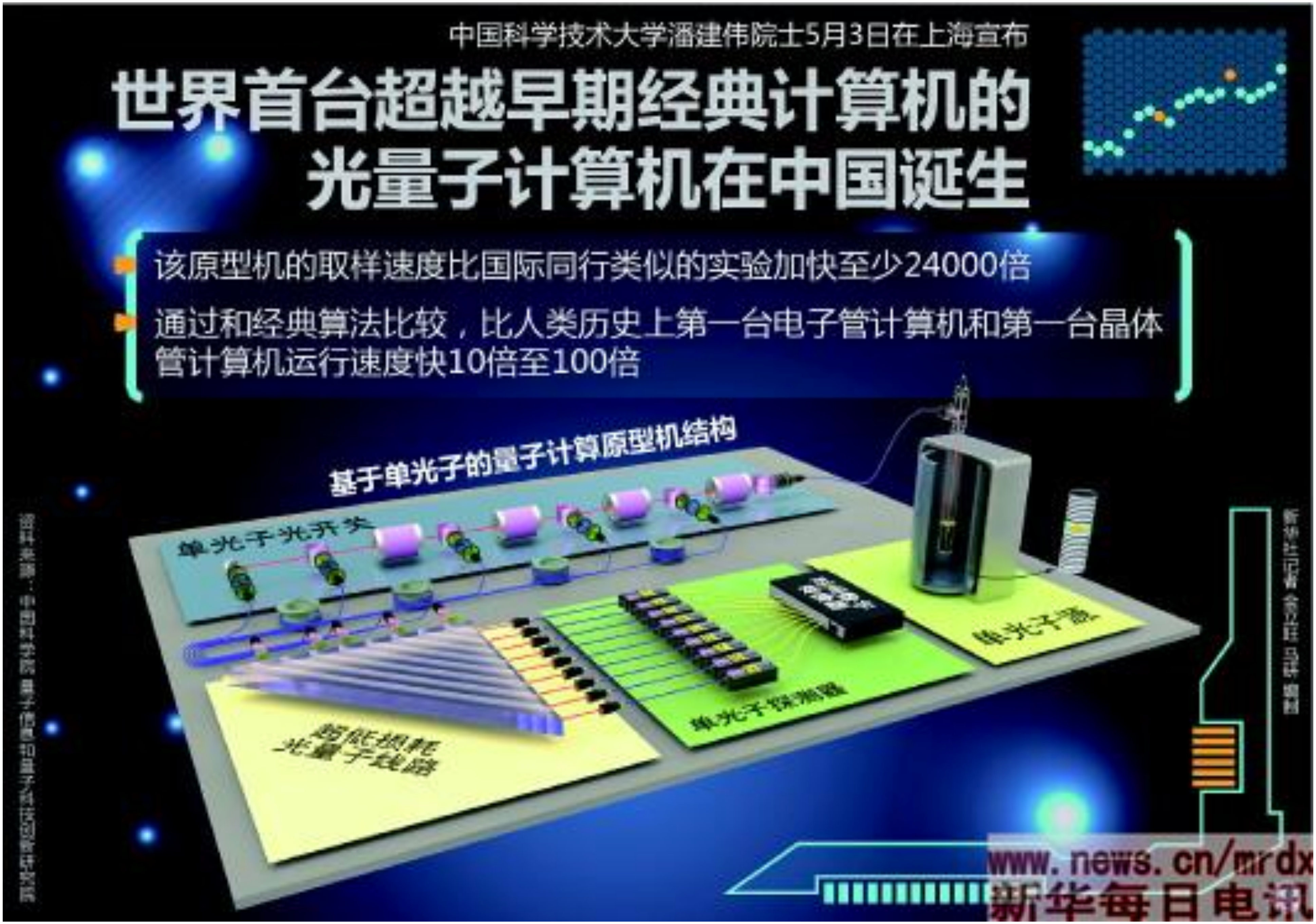
A	1999 – 2004	香港中文大学	物理学本科+硕士
B	2004 – 2009	美国伊利诺伊大学香槟分校 (UIUC)	物理学博士
C	2009 – 2013	美国哈佛大学 --- 化学系	博士后
D	2013 – 2015	清华大学---交叉信息研究院	助理教授
~A	2016 – current	南方科技大学---物理系	副教授

我的个人学术经历

本科⇨研究院⇨大学教授

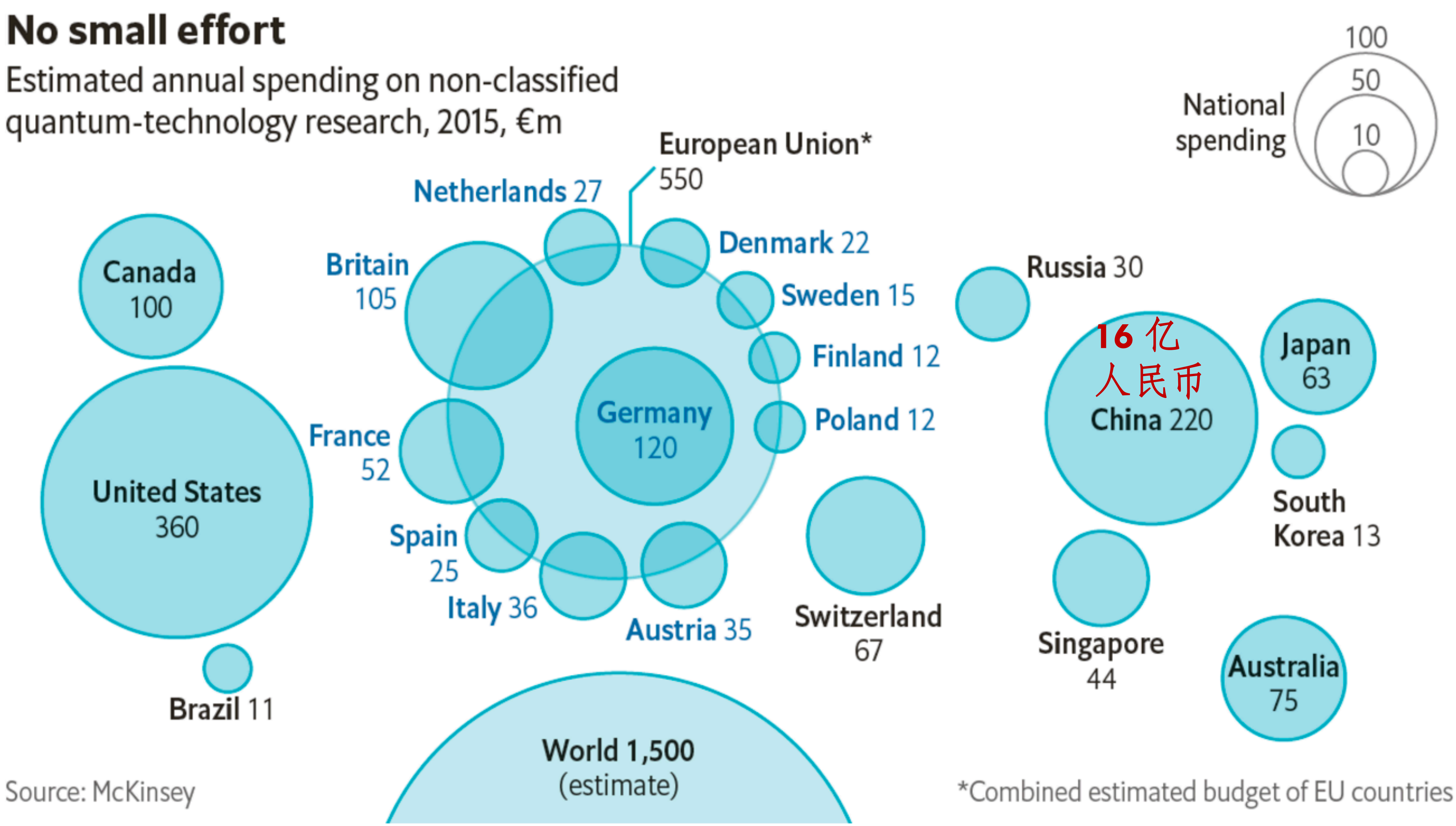
量子科学实验卫星“墨子”

2016年8月16日



中国科学技术大学潘建伟院士5月3日在上海宣布
世界首台超越早期经典计算机的
光量子计算机在中国诞生
该原型机的取样速度比国际同行类似的实验加快至少24000倍
通过和经典算法比较，比人类历史上第一台电子管计算机和第一台晶体管计算机运行速度快10倍至100倍
基于单光子的量子计算原型机结构
单光子光开关
单光子源
单光子探测器
超低损耗
光量子线路
资料来源：中国科学院量子信息和量子科技创新研究院
新华社记者 金立旺 马研 编制
www.news.cn/mrdx
新华每日电讯

The Economist 各国对量子科技的经费支持



http://www.economist.com/technology-quarterly/2017-03-09/quantum-devices

各国对量子科技的专利申请

MIT Technology Review

Intelligent Machines

Moore's Law Is Dead. Now What?

Shrinking transistors have powered 50 years of advances in computing—but now other ways must be found to make computers more capable.

by Tom Simonite May 13, 2016

The Telegraph

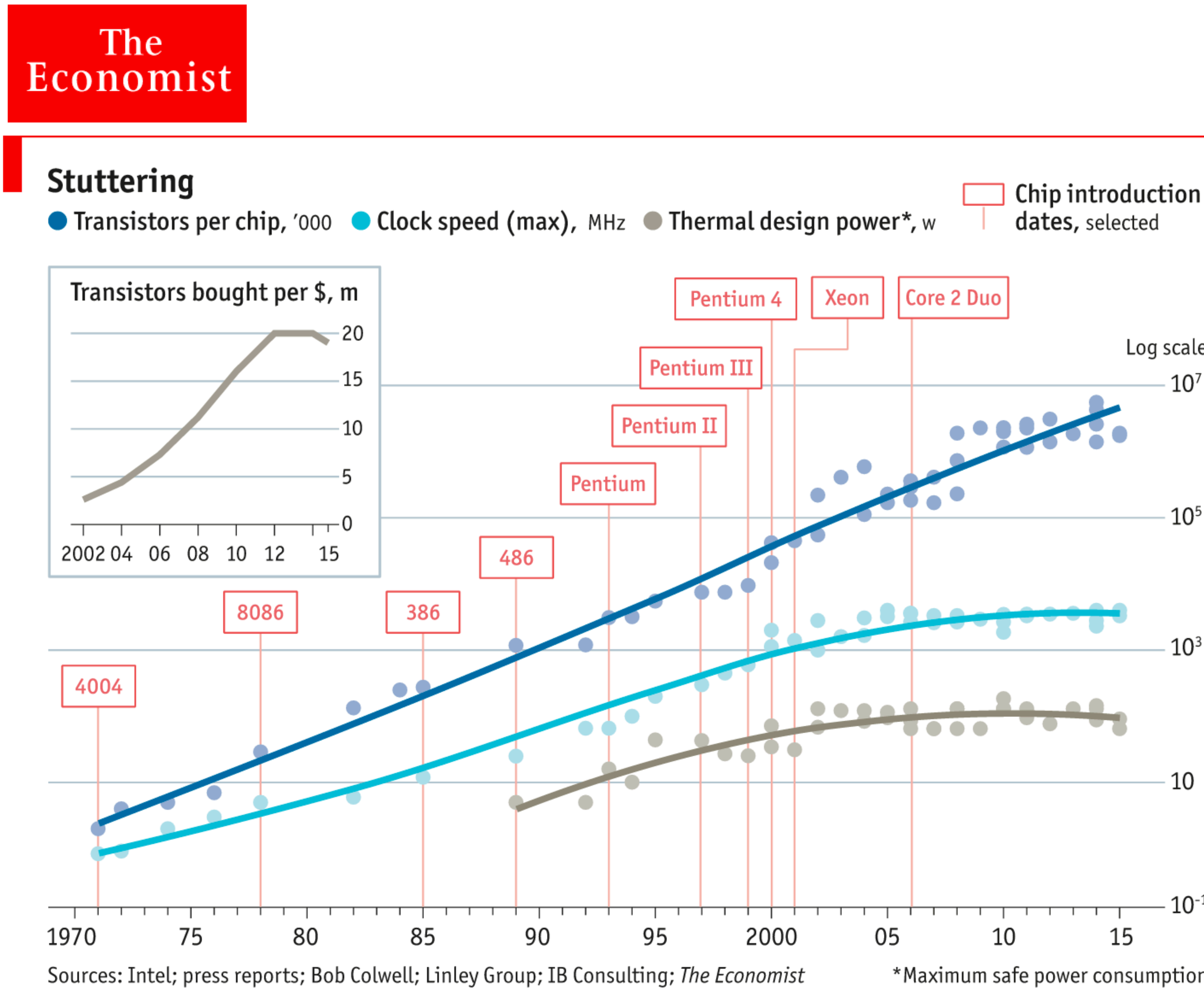
End of Moore's Law? What's next could be more exciting

ars TECHNICA

TECHNOLOGY LAB —

Moore's law really is dead this time

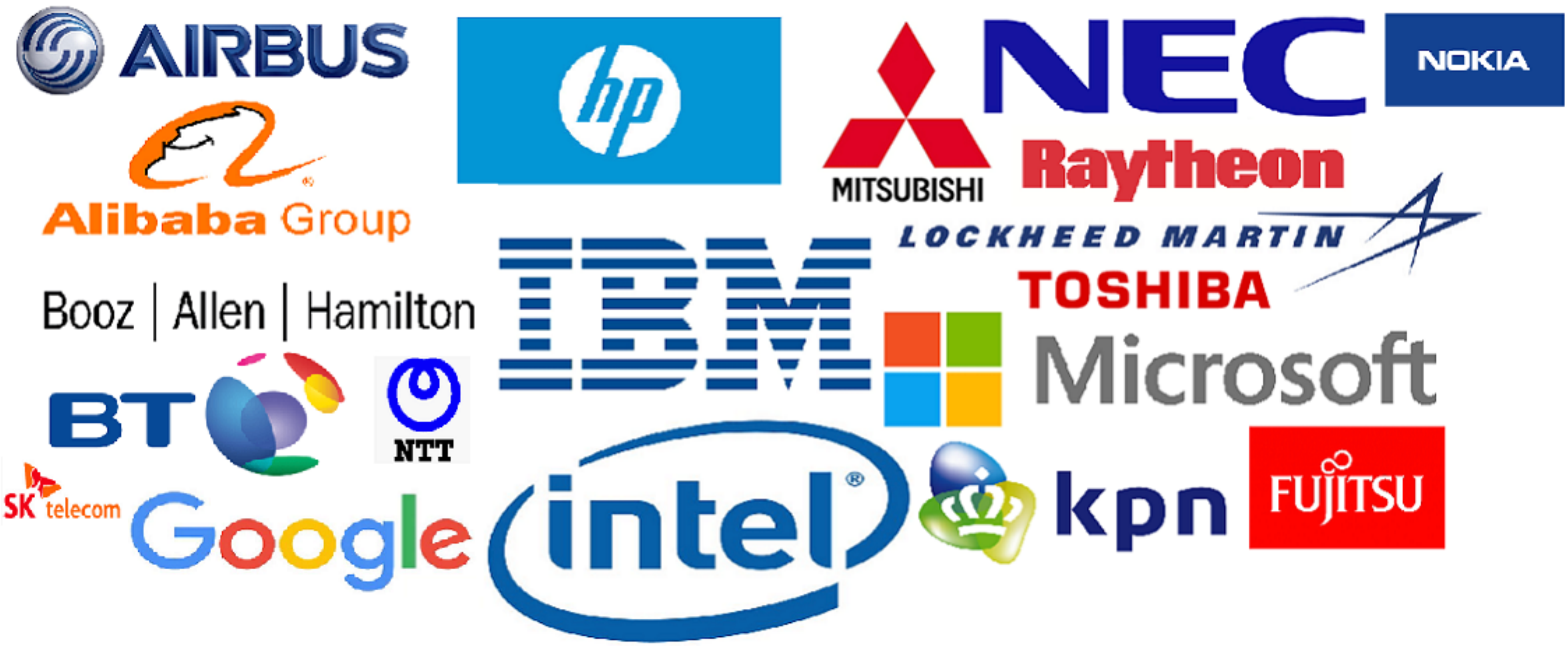
The chip industry is no longer going to treat Gordon Moore's law as the target to aim for.



http://www.economist.com/technology-quarterly/2016-03-12/after-moores-law

SEPTEMBER 13, 2016

18 Corporations Working On Quantum Computing

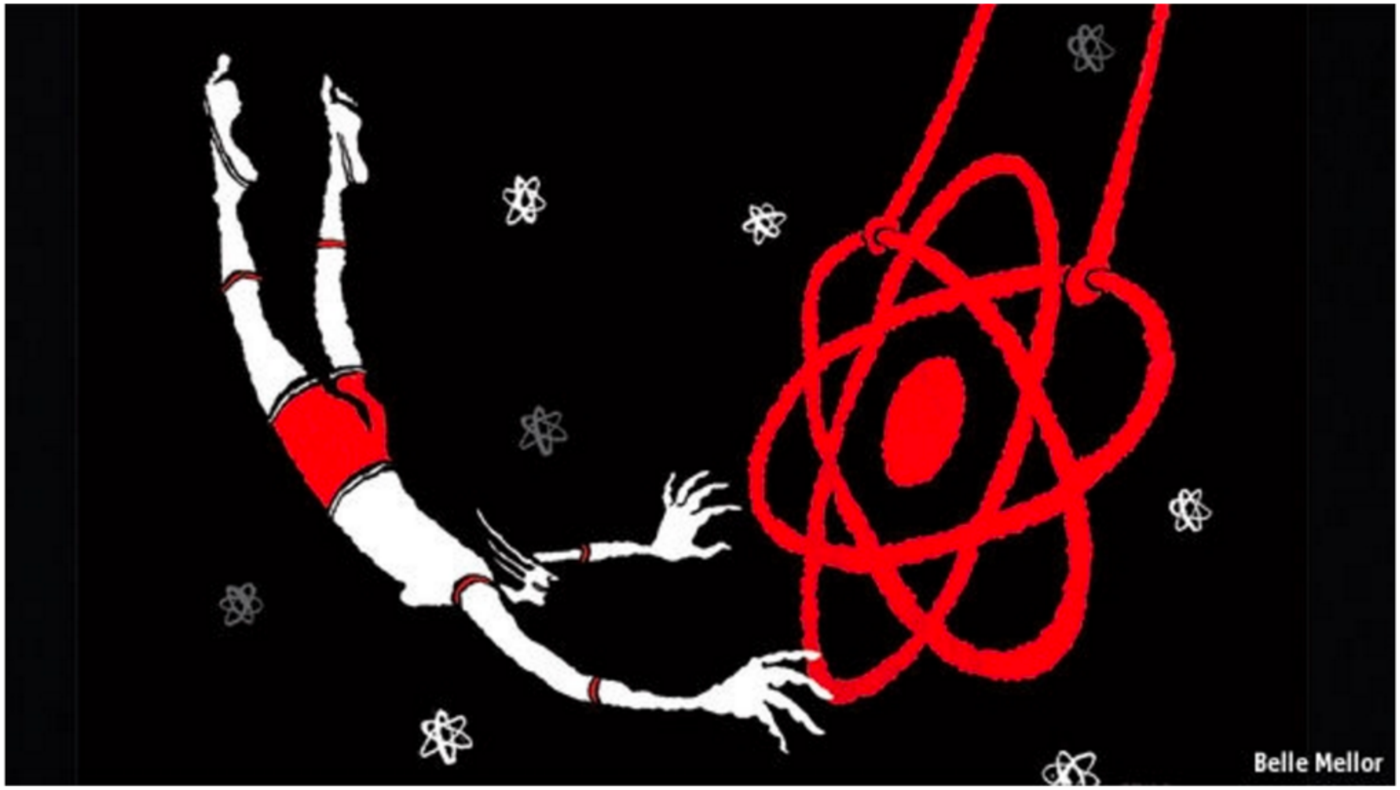


The Economist

Subatomic opportunities

Quantum leaps

The strangeness of the quantum realm opens up exciting new technological possibilities



量子技术的「承诺」

The Economist

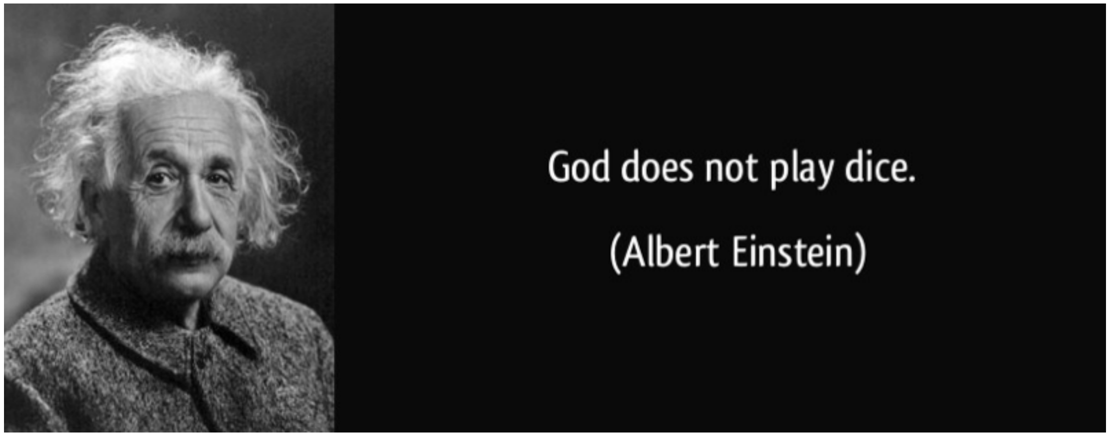
- 一个可以观察单个神经元的帽子，允许其他人监视佩戴者的思想
- 一个可以发现隐藏的核潜艇的传感器
- 一台可以发现新药，革新证券交易和设计新材料的计算机
- 一个通信链路的全球网络，其安全性是由牢不可破的物理定律承保

量子技术的「承诺」 The Economist

- 一个可以观察单个神经元的帽子，允许其他人监视佩戴者的思想
  - 量子机器学习
- 一个可以发现隐藏的核潜艇的传感器
  - 量子照明、量子感应
- 一台可以发现新药，革新证券交易和设计新材料的计算机
  - 量子计算机、量子模拟器
- 一个通信链路的全球网络，其安全性是由牢不可破的物理定律承保
  - 量子通信

量子理论的特性一：

非决定论 indeterminism



量子理论的特性一：

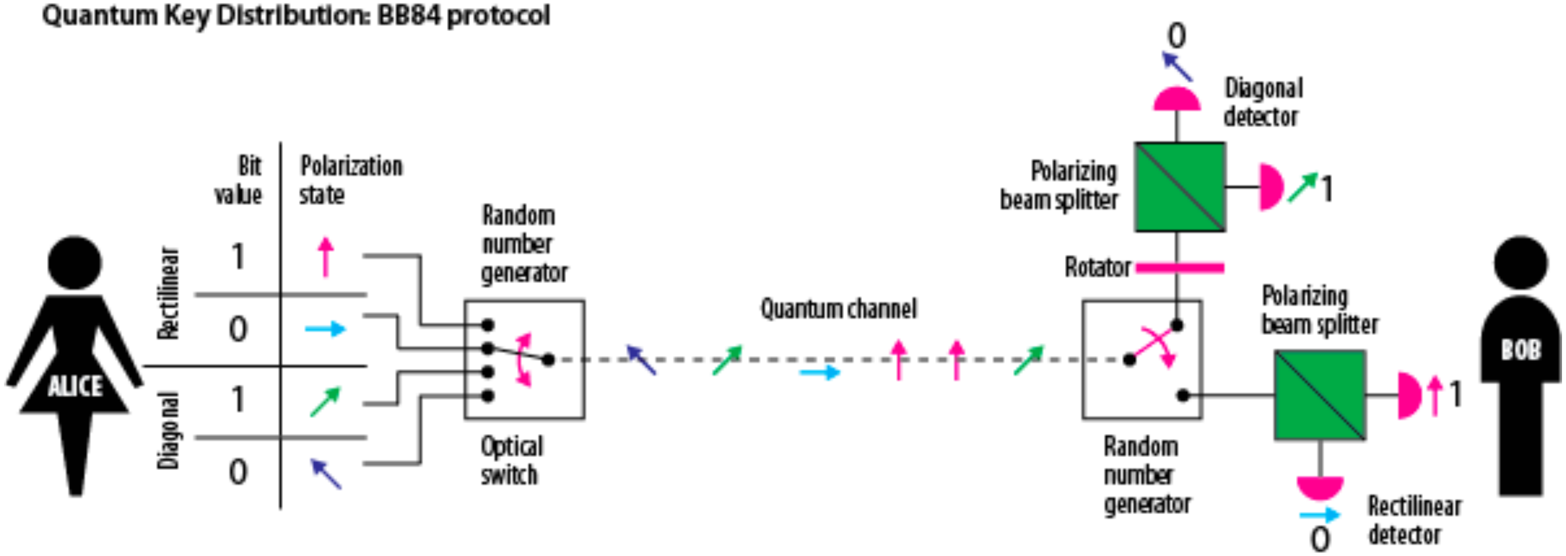
非决定论 indeterminism

应用：保护信息安全

（秘钥分发）

Bennett & Brassard (BB) 84 协议

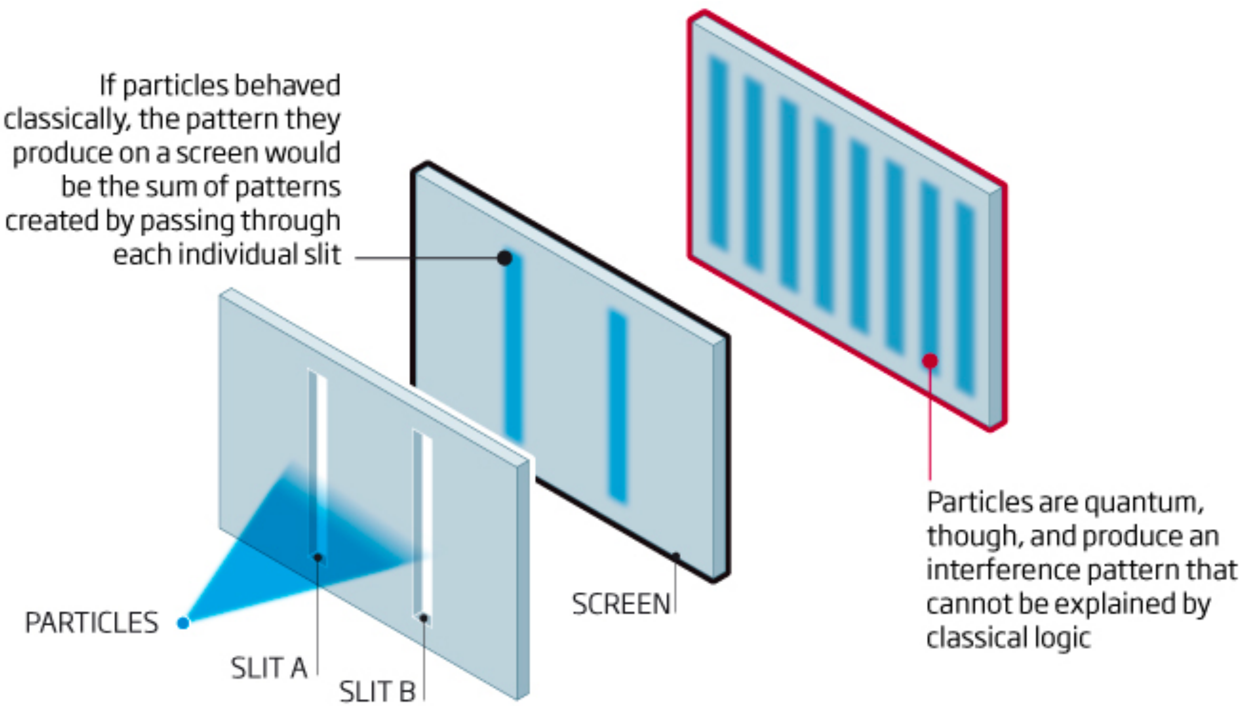
Quantum Key Distribution: BB84 protocol



Quantum transmission & detection	ALICE sends photons	↖	↗	→	↑	↑	↗	↖	↑
	ALICE's random bits	0	1	0	1	1	1	0	1
	BOB's detection events	↑	↗	↖	↑	↗	↗	↖	↖
	BOB's detected bit values	1	1	0	1	1	1	0	0
Public discussion (i.e., sifting)	BOB tells ALICE the basis choices he made	Rect	Diag	Diag	Rect	Diag	Diag	Diag	Diag
	ALICE tells BOB which bits to keep		✓		✓		✓	✓	
	ALICE and BOB's shared sifted key	–	1	–	1	–	1	0	–

量子的特性二：

量子干涉 interference



量子的特性二： 量子干涉 interference

《薛定谔的猫》的思考

量子的特性二： 量子干涉 interference

应用：量子计算机

QUANTUM COMPUTING

Devices based on subatomic physics could make calculations far faster than conventional machines — if nothing spoils their quantum weirdness.

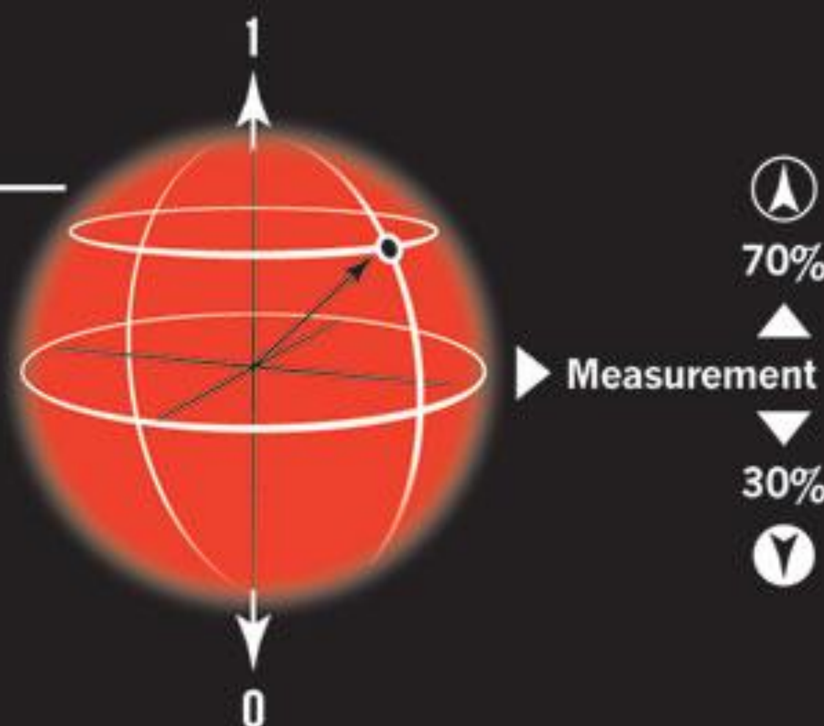
1. SUPERPOSITION

Bits

A classical computer encodes information in strings of 'bits', which can take one of two values: 0 or 1.

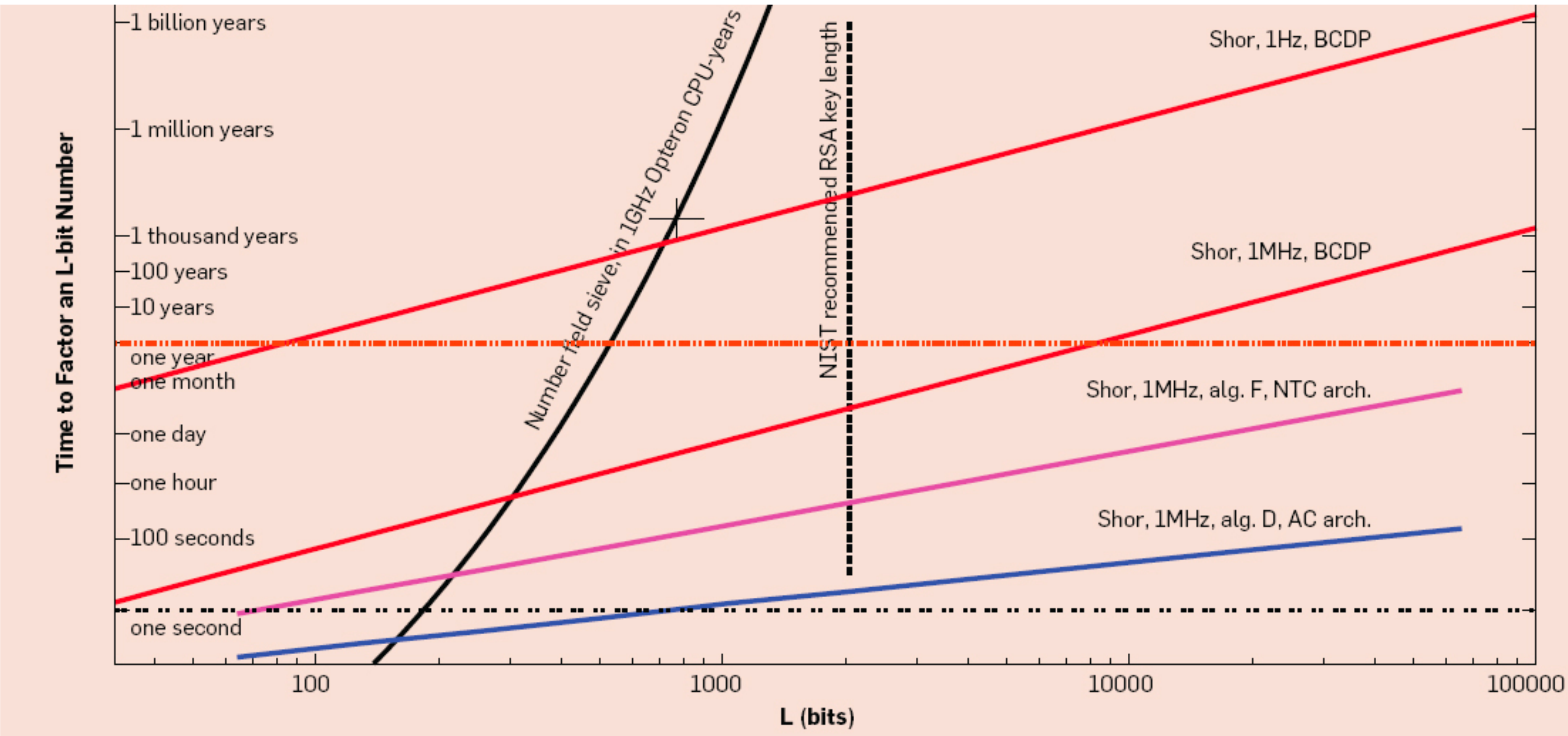
Qubits

Quantum 'qubits' can be encoded by, say, the up or down spin of a particle, and can exist as a superposition of 0 and 1 simultaneously (represented by the fuzzy sphere).

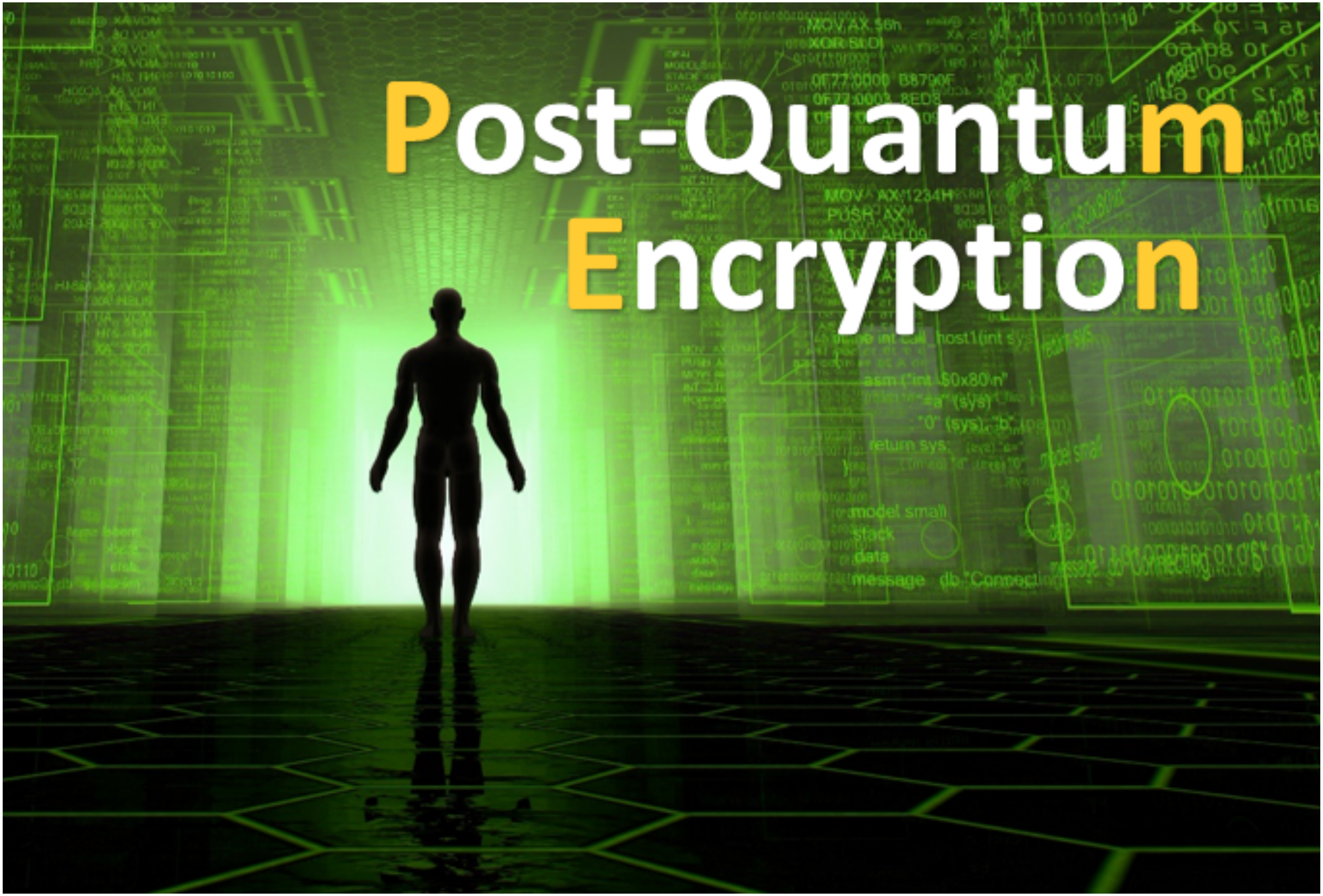


When it is measured, a qubit will collapse into a 0 or 1. The probability of each outcome depends on where the qubit is on the sphere.

利用量子计算机破解密码系统



2011年7月
2011年7月5日，李克强同志视察中国科学技术大学期间，试用了量子保密电话，对量子通信技术研究和产品开发取得的成就表示祝贺，并希望尽快打开市场，打出品牌
Brassard
@HKU 2017


Post-Quantum
Encryption

谷歌的五年量子计算机「商业化」计划

nature International weekly journal of science

NATURE | COMMENT

Commercialize quantum technologies in five years

Masoud Mohseni, Peter Read, Hartmut Neven, Sergio Boixo, Vasil Denchev, Ryan Babbush, Austin Fowler, Vadim Smelyanskiy & John Martinis

谷歌：量子计算机的困境

- 如果要用量子计算机分解 2000 bit 的数字：

- 假设操作误差为 0.01%

- 需要 10^8 量子比特

谷歌：早期量子计算设备的三个商业用途

1. 量子模拟器

   Quantum simulator

2. 基于量子的优化的方法

   Quantum-assisted optimization

3. 量子采样

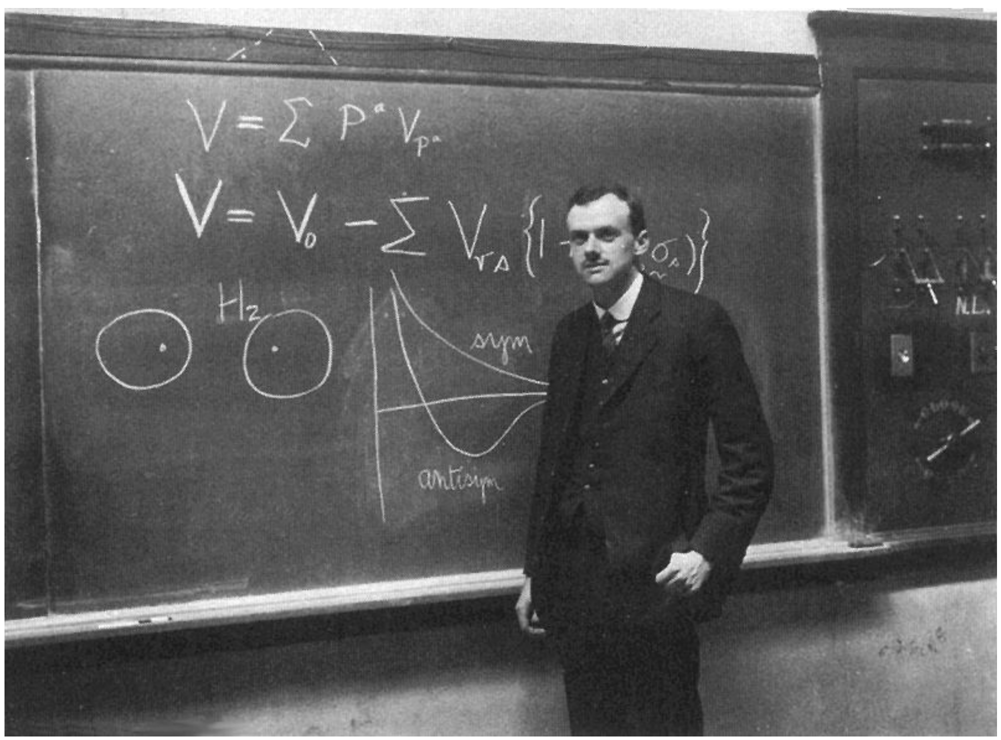
   Quantum Sampling

"… we plan to provide access to our quantum processors through cloud services …"

量子模拟的主要应用（一）：

量子化学

$$H_{\mathrm{mol}}(\mathbf{R}) = \sum_{pq} h_{pq} a_p^\dagger a_q + \frac{1}{2}\sum_{pqrs} h_{pqrs} a_p^\dagger a_q^\dagger a_r a_s$$



量子模拟的主要应用（一）：

量子化学

"For example, algorithms are already known (such as the 'quantum variational eigensolver' approach) that seem to be immune to qubit control errors."

nature COMMUNICATIONS

ARTICLE

Received 9 Dec 2013 | Accepted 27 May 2014 | Published 23 Jul 2014 DOI: 10.1038/ncomms5213 OPEN

A variational eigenvalue solver on a photonic quantum processor

Alberto Peruzzo[1,*,†], Jarrod McClean[2,*], Peter Shadbolt[1], Man-Hong Yung[2,3], Xiao-Qi Zhou[1], Peter J. Love[4], Alán Aspuru-Guzik[2] & Jeremy L. O'Brien[1]

SCIENTIFIC REPORTS

From transistor to trapped-ion computers for quantum chemistry

M.-H. Yung[1,2*], J. Casanova[3*], A. Mezzacapo[3], J. McClean[2], L. Lamata[3], A. Aspuru-Guzik[2] & E. Solano[3,4]

arXiv.org > quant-ph > arXiv:1506.00443

Quantum Physics

Quantum Implementation of Unitary Coupled Cluster for Simulating Molecular Electronic Structure

Yangchao Shen, Xiang Zhang, Shuaining Zhang, Jing-Ning Zhang, Man-Hong Yung, Kihwan Kim

谷歌团队也跟进

arXiv.org > quant-ph > arXiv:1512.06860

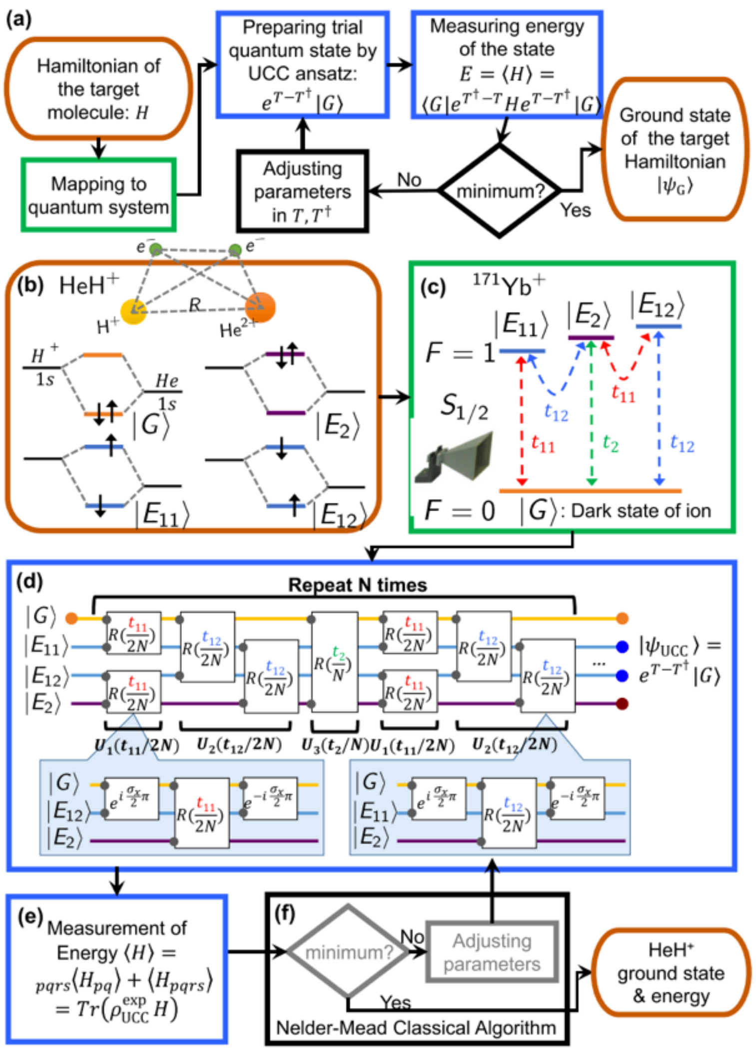
Sea (Help

Quantum Physics

Scalable Quantum Simulation of Molecular Energies

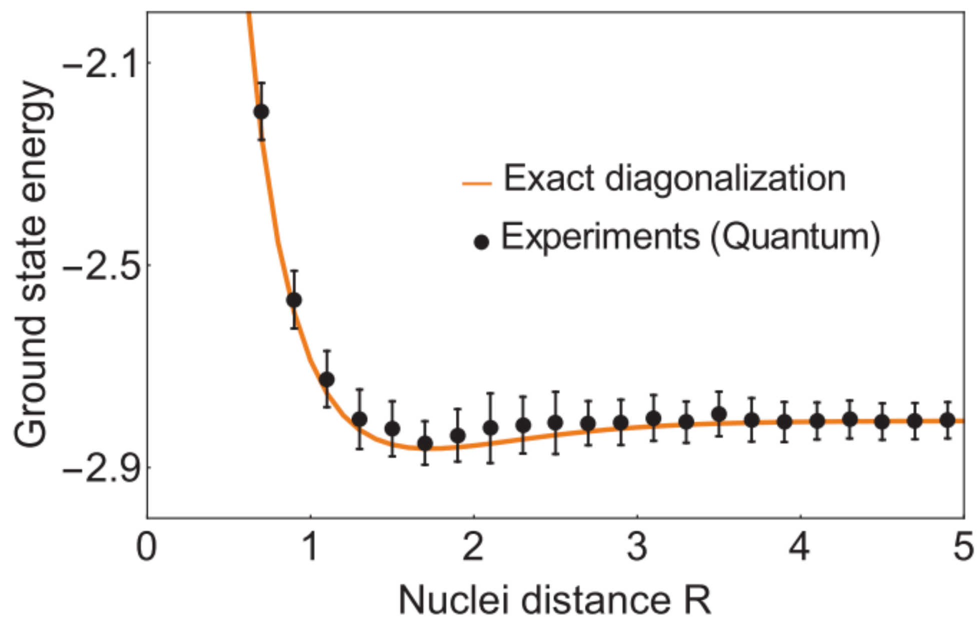
P. J. J. O'Malley, R. Babbush, I. D. Kivlichan, J. Romero, J. R. McClean, R. Barends, J. Kelly, P. Roushan, A. Tranter, N. Ding, B. Campbell, Y. Chen, Z. Chen, B. Chiaro, A. Dunsworth, A. G. Fowler, E. Jeffrey, A. Megrant, J. Y. Mutus, C. Neill, C. Quintana, D. Sank, A. Vainsencher, J. Wenner, T. C. White, P. V. Coveney, P. J. Love, H. Neven, A. Aspuru-Guzik, J. M. Martinis

$$H_{\mathrm{mol}}(\mathbf{R}) = \sum_{pq} h_{pq} a_p^\dagger a_q + \frac{1}{2} \sum_{pqrs} h_{pqrs} a_p^\dagger a_q^\dagger a_r a_s$$



中心思想：

$$\langle H \rangle = \langle H_1 \rangle + \langle H_2 \rangle + \ldots$$



06 Mar 2017

News room > News releases >

IBM Building First Universal Quantum Computers for Business and Science

- IBM unveils roadmap for commercial "IBM Q" quantum systems

"One of the first and most promising applications for quantum computing will be in the area of chemistry and could lead to the discovery of new medicines and materials"

量子模拟的主要应用（二）：

基于量子的优化的方法

工作原理:

量子退火
Quantum annealing

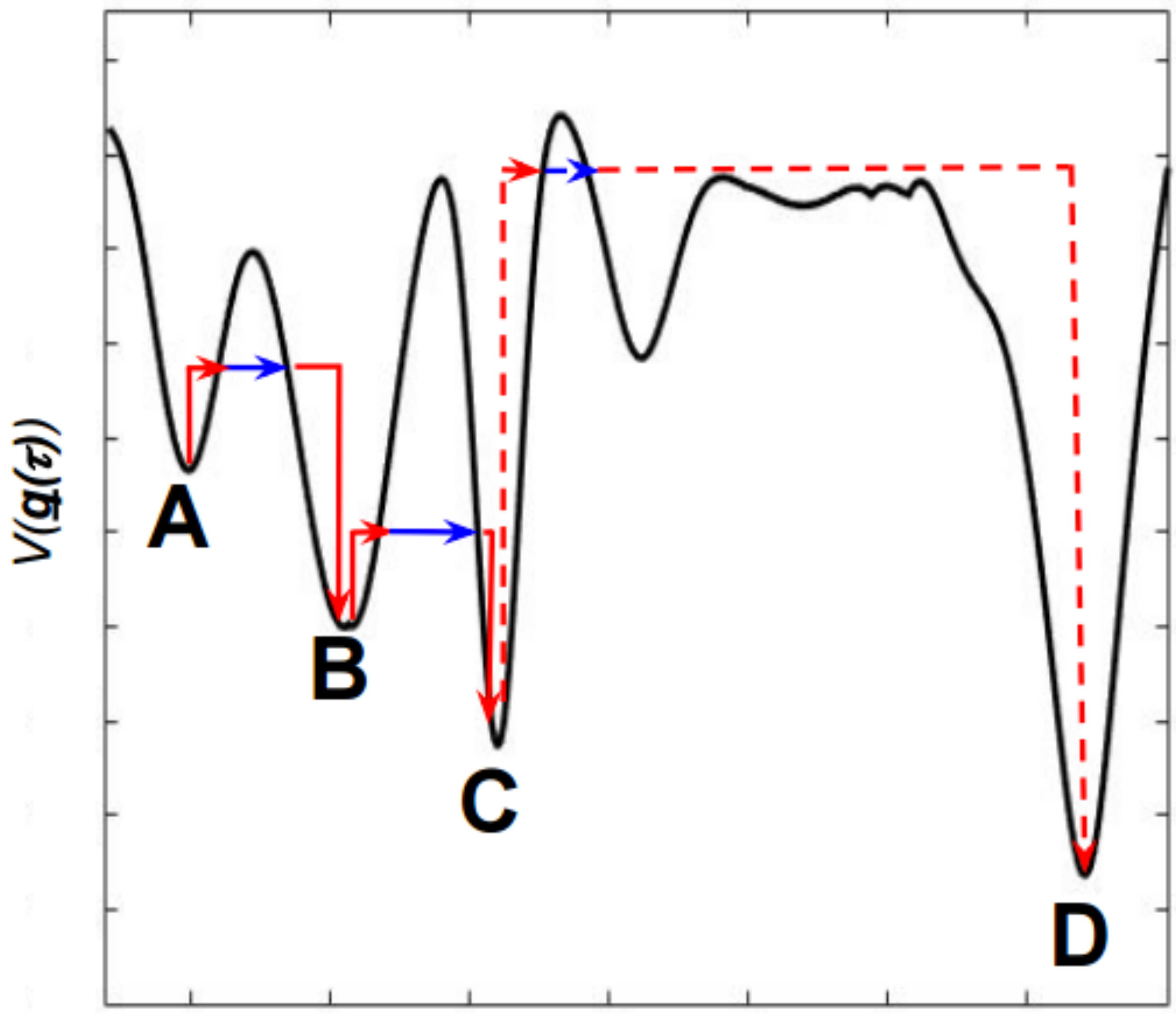
REPORT

A Quantum Adiabatic Evolution Algorithm Applied to Random Instances of an NP-Complete Problem

Edward Farhi[1,*], Jeffrey Goldstone[1], Sam Gutmann[2], Joshua Lapan[3], Andrew Lundgren[3], Daniel Preda[3]
+ See all authors and affiliations

Science 20 Apr 2001:
Vol. 292, Issue 5516, pp. 472-475
DOI: 10.1126/science.1057726

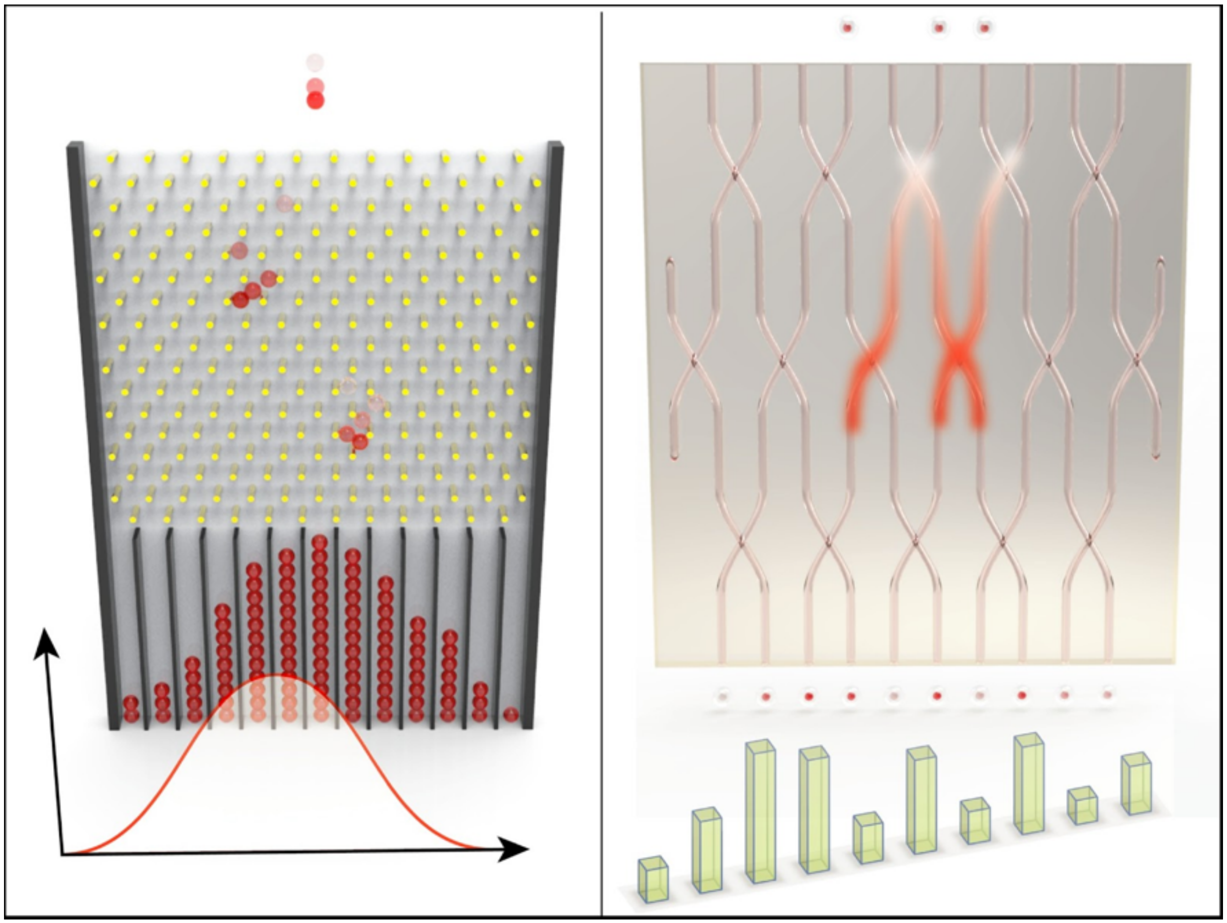
量子退火的工作原理:



	D-Wave One	D-Wave Two	D-Wave 2X	D-Wave 2000Q[45][46]
Available	May 2011	May 2013	August 2015	January 2017
Code-name	Rainier	Vesuvius		
Qubits	128	512	1152	2048
Couplers	352		3000	5600
Josephson junctions	24,000		128,000	
I/O / control lines		192		
Operating temperature		0.02 K	0.015 K	
Power consumption		15.5 kW	25 kW	
Buyers	Lockheed Martin	Lockheed Martin Google/NASA/USRA	Lockheed Martin Google/NASA/USRA Los Alamos National Laboratory	Temporal Defense Systems Inc. Google/NASA/USRA[47] Volkswagen Group[48] Virginia Tech[49]

量子模拟的主要应用:

量子采样(目的：量子霸权)



量子模拟的主要应用：

量子采样

THEORY OF COMPUTING, Volume 9 (4), 2013, pp. 143–252
www.theoryofcomputing.org

The Computational Complexity of Linear Optics*

Scott Aaronson† Alex Arkhipov‡

Received December 2, 2011; Revised December 30, 2012; Published February 9, 2013

Science. **339**: 794
Science. **339**: 798
Nature Photonics. **7**: 540
Nature Photonics. **7**: 545
Science. **349**: 711
Nature Photonics. **8**: 615
Nature Photonics. **8**: 621

量子模拟的主要应用：

量子采样的价值？

机器学习

“Among promising applications of quantum sampling are inference and pattern recognition in machine learning.”

我的课题组目前主要方向：

1. 量子模拟
2. ~~基于量子的优化的方法~~
3. 量子采样
4. 量子机器学习
5. 量子热力学
6. ADS/CFT, 黑洞信息问题？

ADS/CFT, Quantum Information, and Quantum Gravity

Shenzhen, SUSTC - Postdoc

Field of Interest: gr-qc, hep-th, quant
Deadline: 2017-04-30 (PASSED)
Region: Asia

Job description:
ADS/CFT, Quantum Information, and Quantum Gravity

Shenzhen, SUSTC - Postdoc

Job description:

One postdoctoral position in ADS/CFT, Quantum Information, and Quantum Gravity at SUSTech (Southern University of Science and Technology) in Shenzhen.

The "Quantum Information" and "Classical and Quantum Gravity" groups at SUSTech (Shenzhen, China) are looking for a highly motivated postdoc candidate to work on projects related to the interdisciplinary area: ADS/CFT, quantum entanglement, and quantum gravity. The groups
are led by Prof. Man-Hong Yung and Prof. Leonardo Modesto

nature photonics

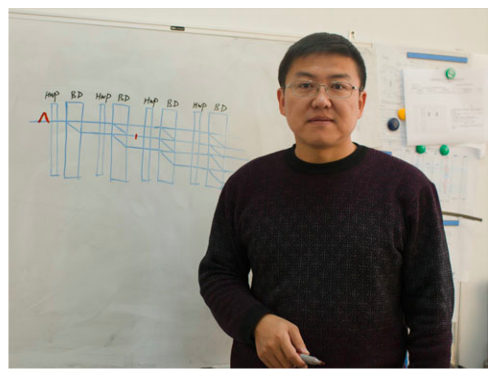
LETTERS

PUBLISHED ONLINE: 19 JANUARY 2014 | DOI: 10.1038/NPHOTON.2013.354

Demon-like algorithmic quantum cooling and its realization with quantum optics

Jin-Shi Xu[1†], Man-Hong Yung[2,3†], Xiao-Ye Xu[1], Sergio Boixo[1], Zheng-Wei Zhou[1], Chuan-Feng Li[1*], Alán Aspuru-Guzik[3*] and Guang-Can Guo[1]






ENTROPIES

Quantum Thermodynamics

$$\rho = \frac{e^{-\beta H}}{\mathrm{tr} e^{-\beta H}}$$

Quantum Information theory

$$S = -\mathrm{tr}\rho \ln \rho$$

quantum entanglement (?)

Maxwell's demon

Statistical Physics

$$S = k_B \ln \Omega$$

Information theory

$$S = -\sum_k p_k \ln p_k$$

$$S = -k_B \sum \frac{1}{\Omega} \ln \frac{1}{\Omega}$$

SHORT PROOF 2$^{\text{ND}}$ LAW

IN THE LANGUAGE OF QUANTUM INFORMATION

Assumptions:

$$\rho_{SB}^{\text{int}} = \rho_S^{\text{int}} \otimes \rho_B^{\text{int}}, \quad \rho_{SB}^{\text{fin}} = U \rho_S^{\text{int}} \otimes \rho_B^{\text{int}} U^\dagger$$

$$S = -\text{tr}\rho \ln \rho$$

$$\mathcal{S}(\rho_A) + \mathcal{S}(\rho_B) \geq \mathcal{S}(\rho_{AB})$$

$$\mathcal{S}(\rho_A \otimes \rho_B) = \mathcal{S}(\rho_A) + \mathcal{S}(\rho_B)$$

$$\mathcal{S}(\rho_S^{\text{fin}}) + \mathcal{S}(\rho_B^{\text{fin}}) \geq \mathcal{S}(U\rho_S^{\text{int}} \otimes \rho_B^{\text{int}} U^\dagger) = \mathcal{S}(\rho_S^{\text{int}} \otimes \rho_B^{\text{int}}) = \mathcal{S}(\rho_S^{\text{int}}) + \mathcal{S}(\rho_B^{\text{int}})$$

$$\mathcal{S}(U\rho U^\dagger) = \mathcal{S}(\rho)$$

$$\Rightarrow \quad \underbrace{\mathcal{S}(\rho_S^{\text{fin}}) - \mathcal{S}(\rho_S^{\text{int}})}_{=\Delta\mathcal{S}_S} + \underbrace{\mathcal{S}(\rho_B^{\text{fin}}) - \mathcal{S}(\rho_B^{\text{int}})}_{=\Delta\mathcal{S}_B} \geq 0$$

南科大/深圳
在量子科技的布局

南科大量子计算团队

俞大鹏院士
南科大量子科学与工程中心主任

南科大量子计算团队

理论方向：

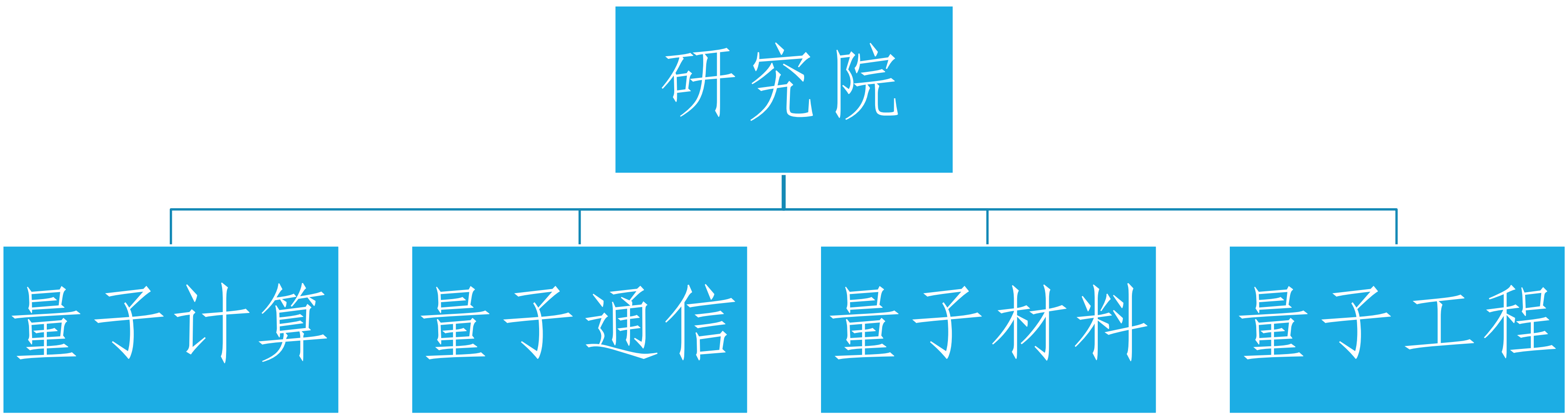
- 翁文康（量子计算）
- Oscar Dahslten （量子信息）
- 吴健生 （超导量子计算）

实验方向：

- 陈远珍（超导量子计算）
- xxx NMR 核磁量子计算
- yyy 光量子计算

深圳市
量子科学与工程研究院
（五月挂牌）

深圳市
量子科学与工程研究院



*大量职位空缺

谢谢！