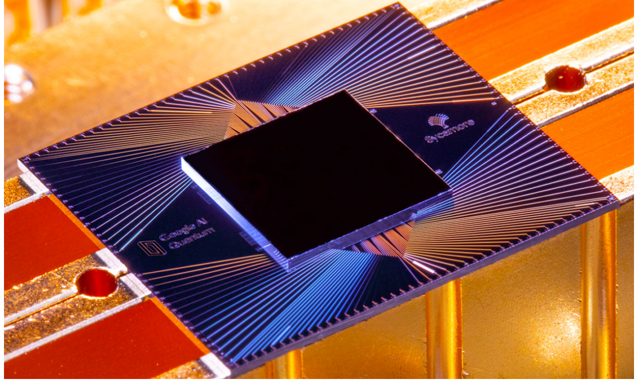
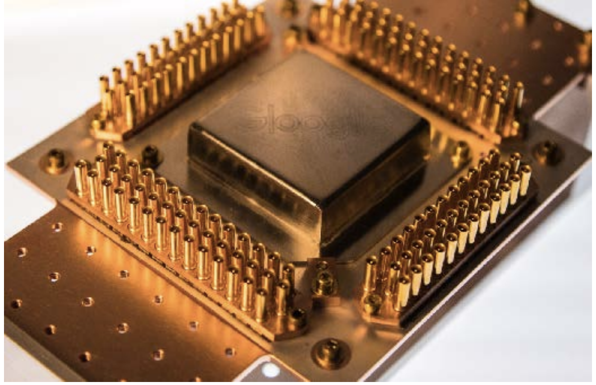
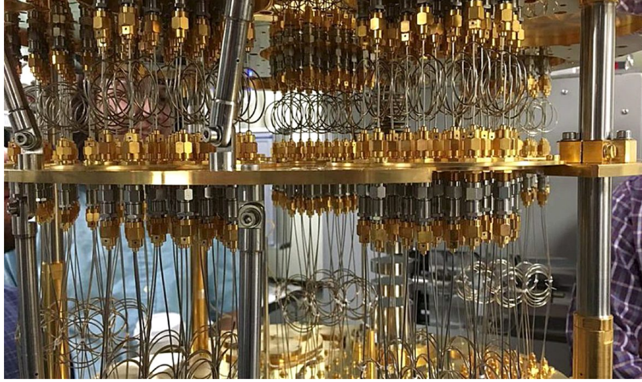




О статье
"Quantum supremacy using a programmable superconducting processor”
by Google AI Quantum and collaborators

Лев Николаевич Щур

Профессор и заведующий, кафедра ПИКСиС,
научный руководитель магистерской программы
«Суперкомпьютерное моделирование в науке и инженерии»
Московский институт электроники и математики им. А.Н.Тихонова
Высшая школа экономики

Российская Академия Наук

ВЦ РАН

МИЭМ Московский институт электроники и математики НИУ ВШЭ

Milestone

R.P. Feynman,
Simulating physics with computers,
Int. J. Theor. Phys. 21 (1982) 467

"If we suppose that we know all the physical laws perfectly, of course we don't have to pay any attention to computers"

"… classical physics is *local*, *causal*, and *reversible*, and therefore apparently quite adaptive to computer simulation."

"… every new idea, it **takes a generation or two** until it becomes obvious that there's no real problem."

Milestone

R.P. Feynman,
Simulating physics with computers,
Int. J. Theor. Phys. 21 (1982) 467

"… I know that quantum mechanics seem to involve probability --- and I therefore want to talk about simulation probability."

"… one way that we could have a computer that simulates a probabilistic theory, something that has a probability in it, would be to calculate the probability and then interpret this number to represent nature."

Milestone

R.P. Feynman, Simulating physics with computers, Int. J. Theor. Phys. 21 (1982) 467

what it's doing in all other regions. For example, suppose there are variables in the system that describe the whole world (x_A, x_B)—the variables x_A you're interested in, they're "around here"; x_B are the whole result of the world. If you want to know the probability that something around here is happening, you would have to get that by integrating the total probability of all kinds of possibilities over x_B. If we had *computed* this probability, we would still have to do the integration

$$P_A(x_A) = \int P(x_A, x_B)\, dx_B$$

which is a hard job! But if we have *imitated* the probability, it's very simple to do it: you don't have to do anything to do the integration, you simply disregard what the values of x_B are, you just look at the region x_A. And

Milestone

R.P. Feynman, Simulating physics with computers, Int. J. Theor. Phys. 21 (1982) 467

therefore, the problem is, how can we simulate the quantum mechanics? There are two ways that we can go about it. We can give up on our rule about what the computer was, we can say: Let the computer itself be built of quantum mechanical elements which obey quantum mechanical laws. Or we

4. QUANTUM COMPUTERS—UNIVERSAL QUANTUM SIMULATORS

Milestone

Quantum supremacy using a programmable superconducting processor

Google AI Quantum and collaborators†

Author contributions The Google AI Quantum team conceived of the experiment. The applications and algorithms team provided the theoretical foundation and the specifics of the algorithm. The hardware team carried out the experiment and collected the data. The data analysis was done jointly with outside collaborators. All authors wrote and revised the manuscript and supplement.

Paper leaked 21.09.2019
Supplemental material dated 22.07.2019

Milestone

Quantum supremacy using a programmable superconducting processor

Google AI Quantum and collaborators†

1. Google Research,
2. University of Massachusetts Amherst,
3. Quantum Artificial Intelligence Lab., NASA Ames Research Center,
4. Institute for Quantum Information and Matter, Caltech,
5. University of California, Santa Barbara,
6. Friedrich-Alexander University Erlangen-Nuernberg, Germany,
7. Quantum Computing Institute, Oak Ridge National Laboratory,
8. Juelich Supercomputing Centre, Germany,
9. University of Illinois at Urbana-Champaign.

Head – Prof. John Martinis (UC Santa Barbara)

Leaked by – Dr. Eleanor G. Rieffel (NASA) computers [1]. Realizing Feynman's vision poses significant experimental and theoretical challenges. First, can a quantum system be engineered to perform a computa-tion in a large enough computational (Hilbert) space and with low enough errors to provide a quantum speedup?Second, can we formulate a problem that is hard for a classical computer but easy for a quantum computer? By computing a novel benchmark task on our superconducting qubit processor [2–7], we tackle both questions. Our experiment marks a milestone towards full scale quantum computing: quantum supremacy [8].

[8] Preskill, J. Quantum computing and the entanglement frontier. *Rapporteur talk at the 25th Solvay Conference*

Quantum supremacy using a programmable superconducting processor

supremacy also heralds the era of Noisy Intermediate-Scale Quantum (NISQ) technologies. The benchmark task we demonstrate has an immediate application in generating certifiable random numbers [9]; other initial uses for this new computational capability may include optimization optimization [10–12], machine learning [13–15], materials science and chemistry [16–18]. However, To achieve quantum supremacy, we made a number of technical advances which also pave the way towards error correction. We developed fast, high-fidelity gates that can be executed simultaneously across a two-dimensional qubit array. We calibrated and benchmarked the processor at both the component and system level using a powerful new tool: cross-entropy benchmarking (XEB). Finally, we used component-level fidelities to accurately predict the performance of the whole system, further showing that quantum information behaves as expected when scaling to large systems.

[24] Boixo, S. *et al.* Characterizing quantum supremacy in near-term devices. *Nat. Phys.* **14**, 595 (2018).

[25] Aaronson, S. & Chen, L. Complexity-theoretic foundations of quantum supremacy experiments. In *32nd Computational Complexity Conference (CCC 2017)* (2017).

[26] Neill, C. *et al.* A blueprint for demonstrating quantum supremacy with superconducting qubits. *Science* **360**, 195–199 (2018).

[27] Bremner, M. J., Montanaro, A. & Shepherd, D. J. Average-case complexity versus approximate simulation of commuting quantum computations. *Phys. Rev. Lett.* **117**, 080501 (2016).

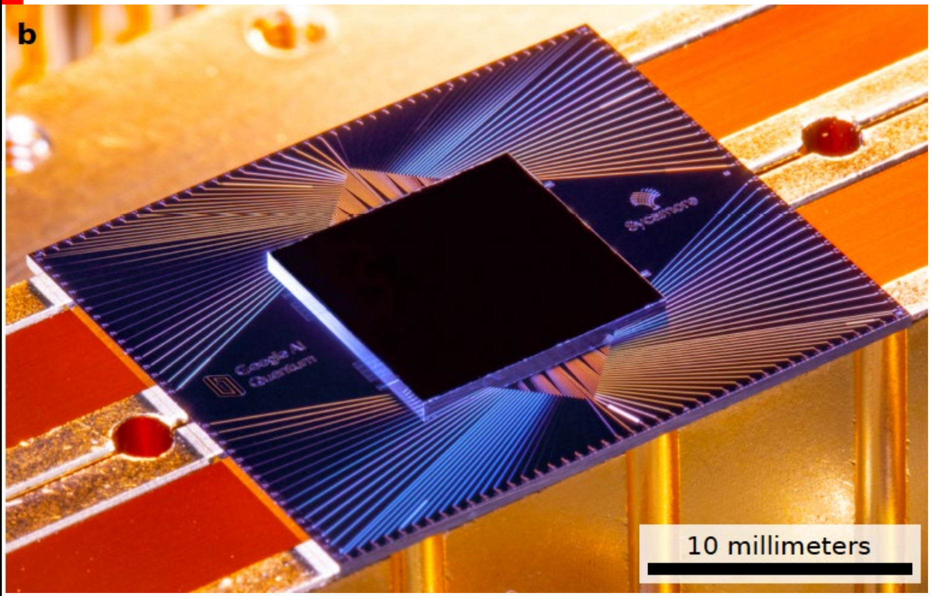
[28] Bouland, A., Fefferman, B., Nirkhe, C. & Vazirani, U. Quantum supremacy and the complexity of random circuit sampling. *Preprint at https://arxiv.org/abs/1803.04402* (2018).

of computational hardness [24, 25, 27, 28]. We design the circuits to entangle a set of quantum bits (qubits) by repeated application of single-qubit and two-qubit logical operations. Sampling the quantum circuit's output produces a set of bitstrings, e.g. $\{0000101, 1011100, \ldots\}$. Due to quantum interference, the probability distribution of the bitstrings resembles a speckled intensity pattern produced by light interference in laser scatter, such that some bitstrings are much more likely to occur than others. Classically computing this probability distribution becomes exponentially more difficult as the number of qubits (width) and number of gate cycles (depth) grows.

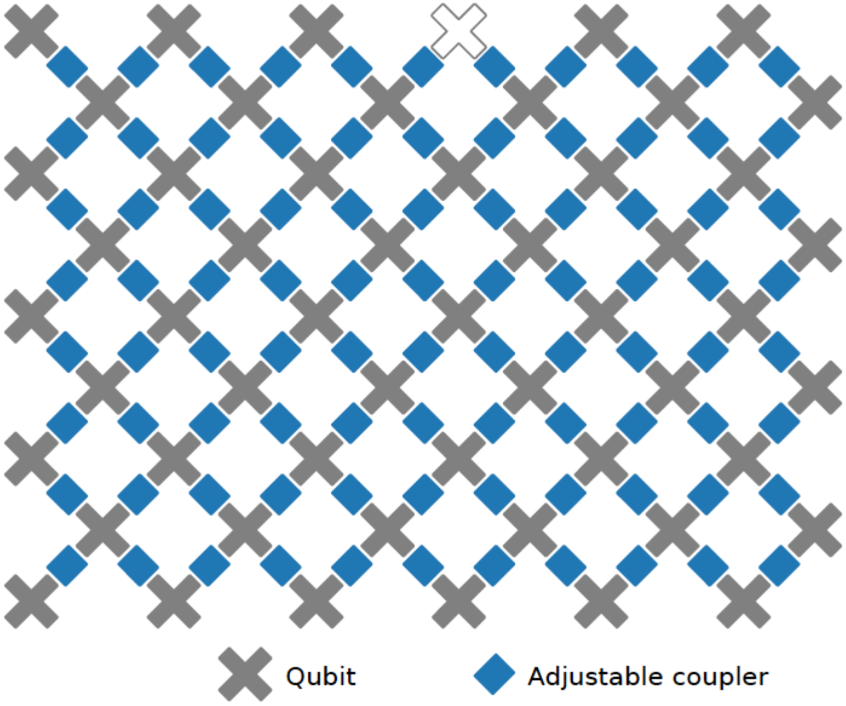
Quantum supremacy using a programmable superconducting processor

We designed a quantum processor named "Sycamore" which consists of a two-dimensional array of 54 trans-mon qubits, where each qubit is tunably coupled to four nearest-neighbors, in a rectangular lattice. The connec-

b



a



Quantum supremacy using a programmable superconducting processor

Our processor uses transmon qubits [6], which can be thought of as nonlinear superconducting resonators at 5 to 7 GHz. The qubit is encoded as the two lowest quan-tum eigenstates of the resonant circuit. Each transmon has two controls: a microwave drive to excite the qubit, and a magnetic flux control to tune the frequency. Each qubit is connected to a linear resonator used to read out the qubit state [5]. As shown in Fig. 1, each qubit is also connected to its neighboring qubits using a new ad-justable coupler [31, 32]. Our coupler design allows us to quickly tune the qubit-qubit coupling from completely off to 40 MHz.

oSince one qubit did not function properly the device uses 53 qubits and 86 couplers.

Российская Академия Наук

ВЦ РАН

МИЭМ Московский институт электроники и математики НИУ ВШЭ

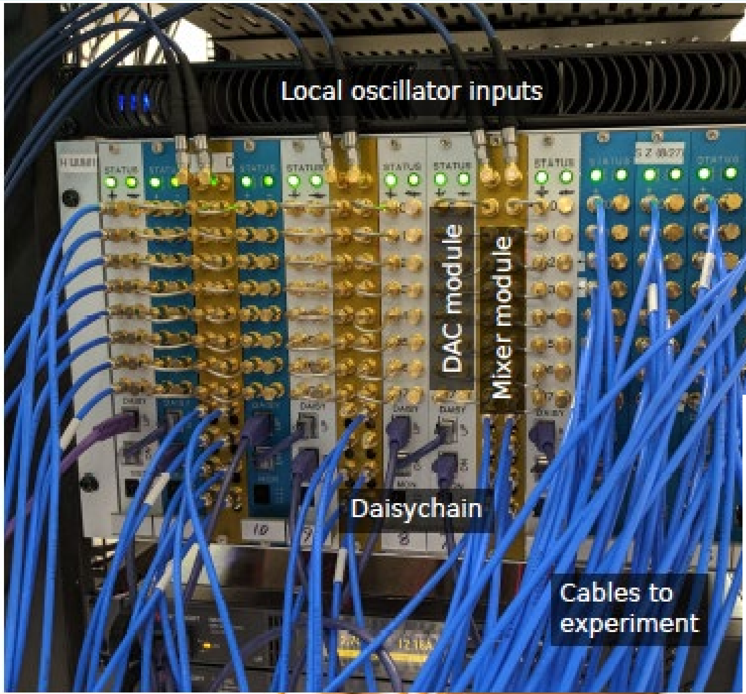
The processor is connected through filters and attenuators to room-temperature electronics, which synthesize the control signals. The state of all qubits can be read simultaneously by using a frequency-multiplexing technique [33, 34]. We use two stages of cryogenic amplifiers to boost the signal, which is digitized (8 bits at 1 GS/s) and demultiplexed digitally at room temperature. In total, we orchestrate 277 digital-to-analog converters (14 bits at 1 GS/s) for complete control of the quantum processor.

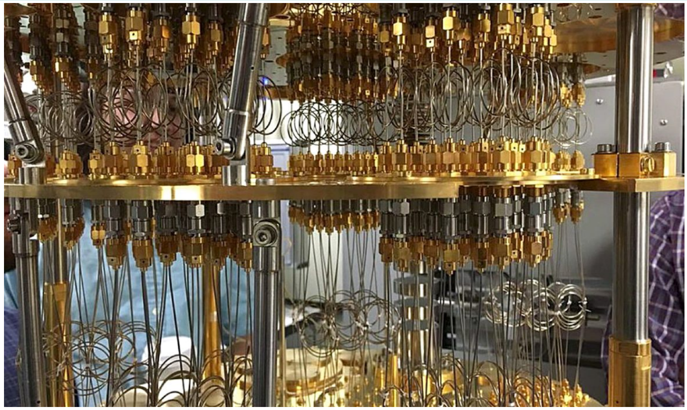
The interaction Hamiltonian of a system of on-resonance transmons with adjustable coupling (truncated to the qubit levels) has the following approximate form,

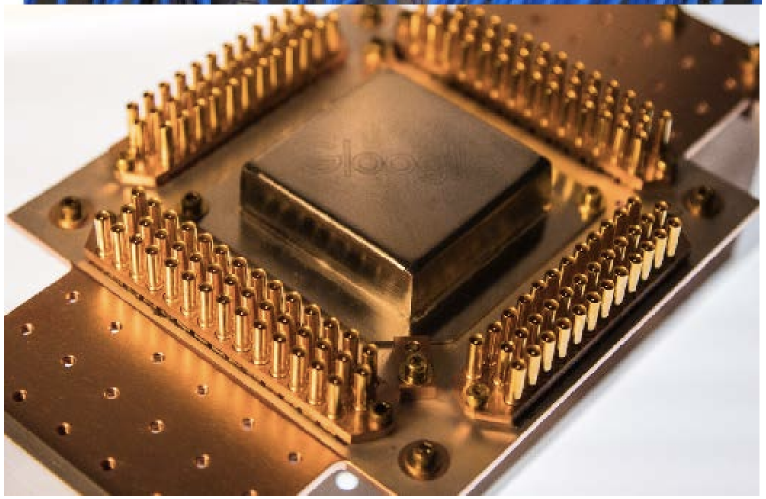
$$H_{\mathrm{int}}(t) \approx \sum_{\langle i,j\rangle} g_{ij}(t)\,(\sigma_i^+\sigma_j^- + \sigma_i^-\sigma_j^+) + \frac{g_{ij}^2(t)}{|\eta|}\,\sigma_i^z\sigma_j^z\,, \quad (1)$$

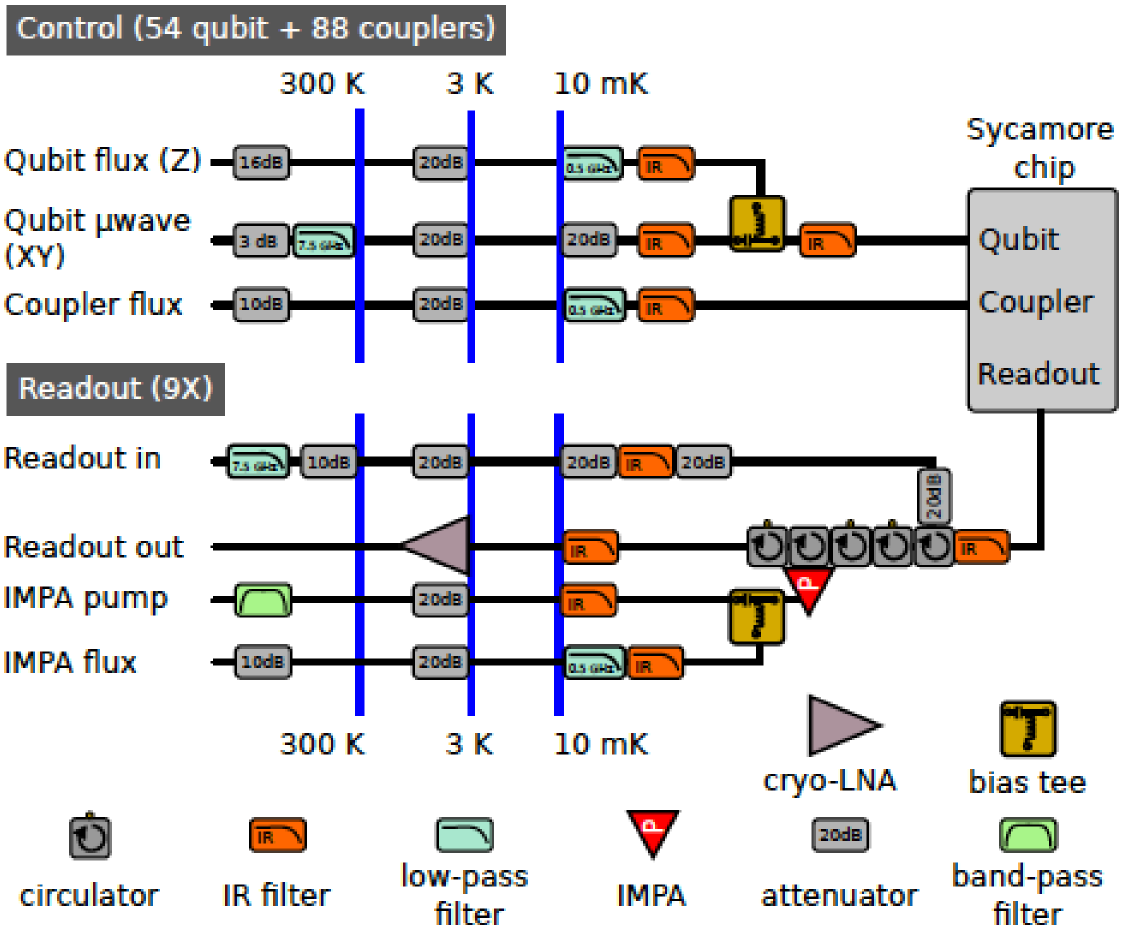
where g_{ij} is the nearest neighbor coupling, η is the non-linearity of the qubits (roughly constant), i and j index nearest-neighbor qubit pairs, and $\sigma^+ + \sigma^- = \sigma^x$. We pulse the coupling in time to create coupling gates.

Quantum supremacy using a programmable superconducting processor









Российская Академия Наук

ВЦ РАН

Quantum supremacy using a programmable superconducting processor

C. Neill, P. Roushan, K. Kechedzhi, S. Boixo, S. V. Isakov, V. Smelyanskiy, A. Megrant, B. Chiaro, A. Dunsworth, K. Arya, *et al.*, A blueprint for demonstrating quantum supremacy with superconducting qubits. Science **360**, 195 (2018).

Random Quantum States

Foundations of Physics, Vol. 20, No. 11, 1990

William K. Wootters[1]

Classical simulations:

- Shroedinger-Feynman simulator
- Feynman simulator
- Juelich simulators

Classical computers

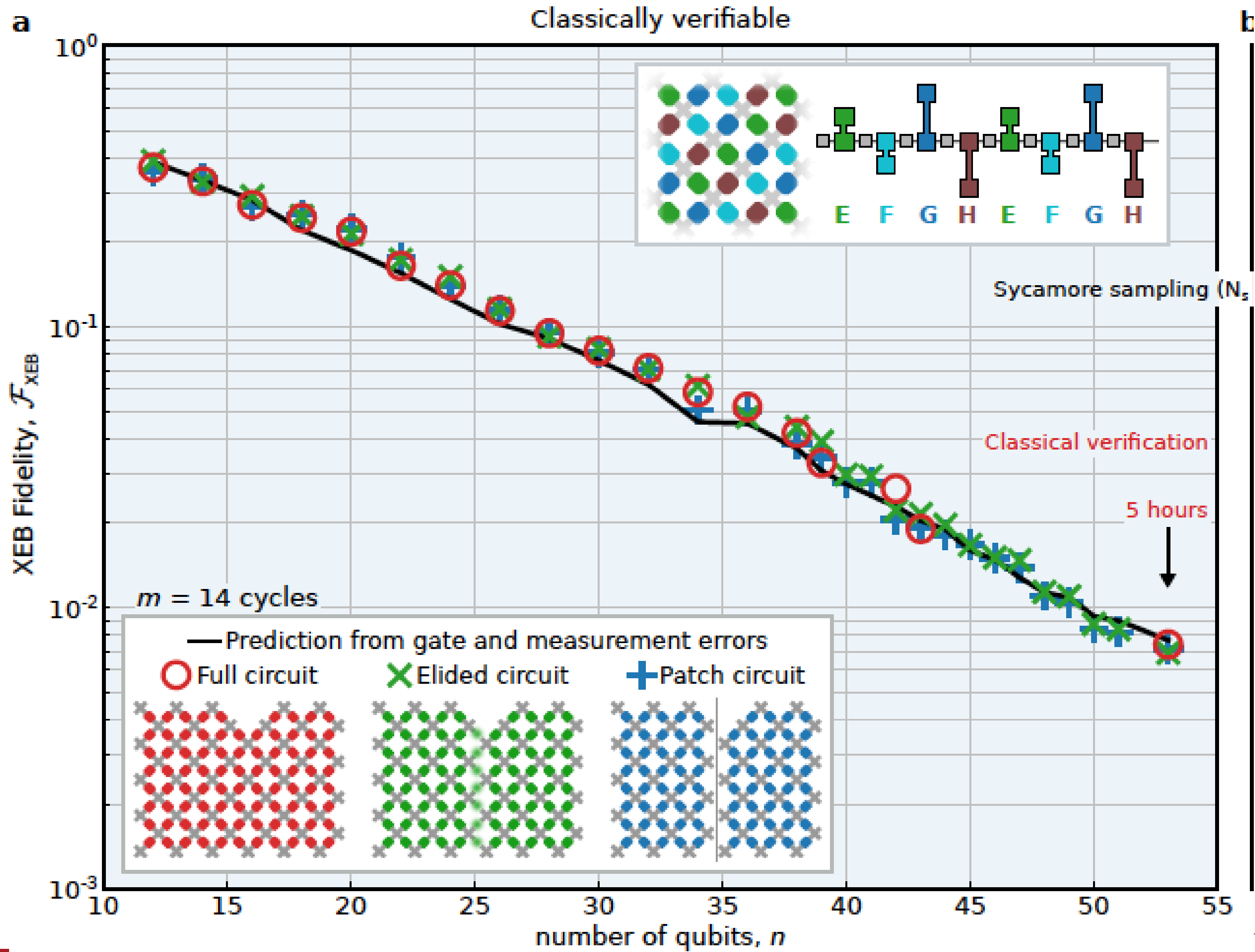
- Summit (IBM AC922 with 2414592 cores – 148.6 Tflops) at Oak Ridge
- JUWELS (Platinum 8168 with 114480 cores – 6.2 Tflops) at Juelich FZJ
- Google data centers

Российская Академия Наук

ВЦ РАН

МИЭМ Московский институт электроники и математики НИУ ВШЭ

Quantum supremacy using a programmable superconducting processor



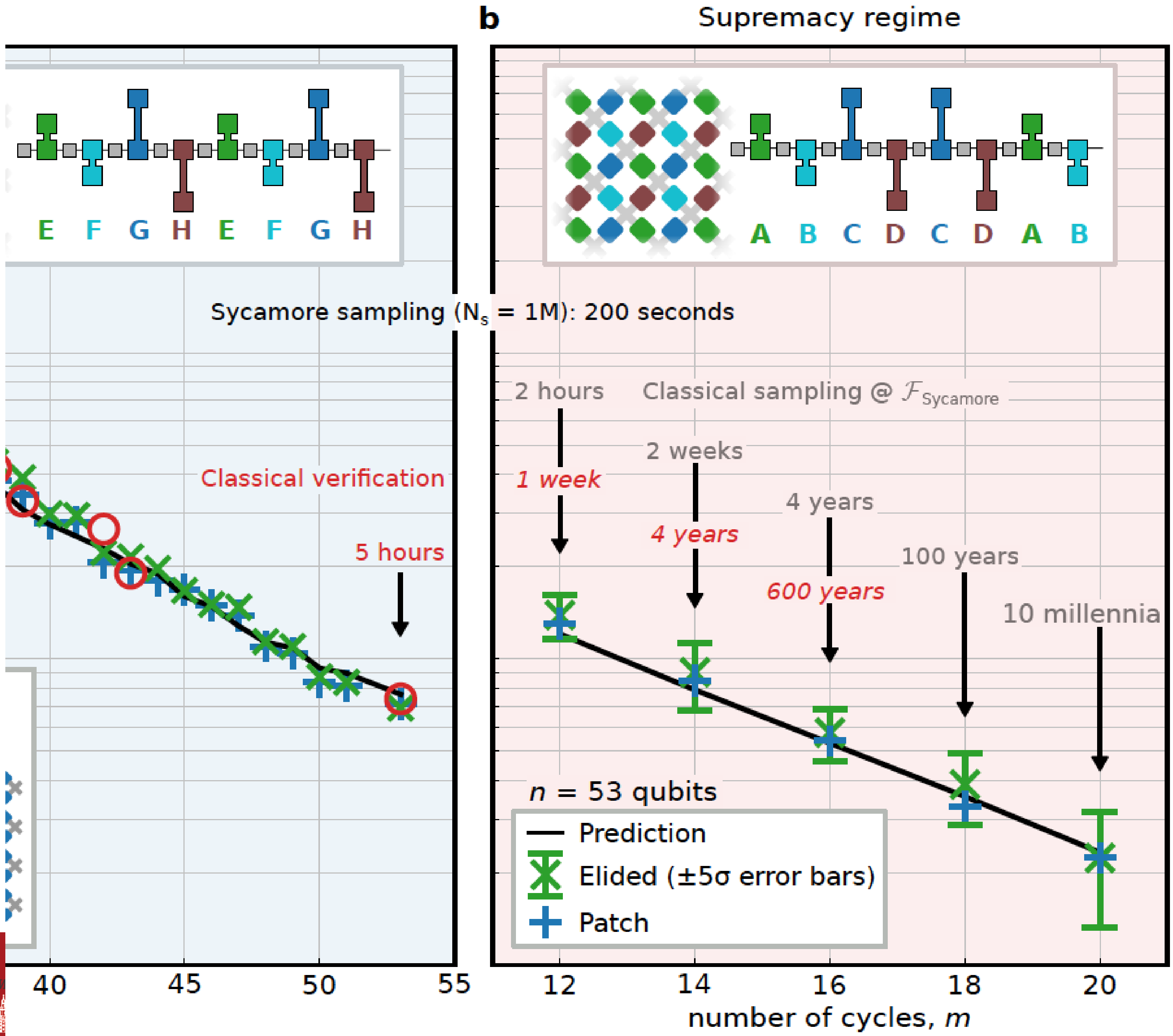
Российская Академия Наук

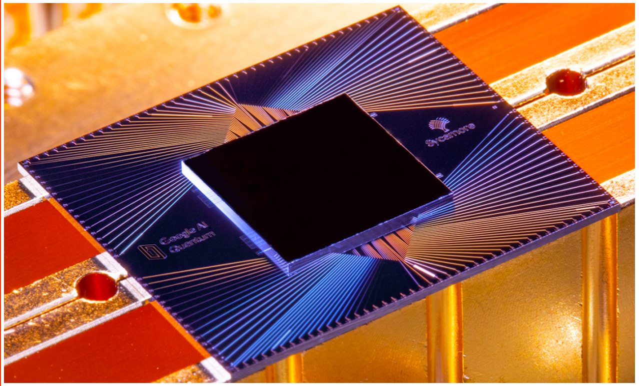
ВЦ РАН

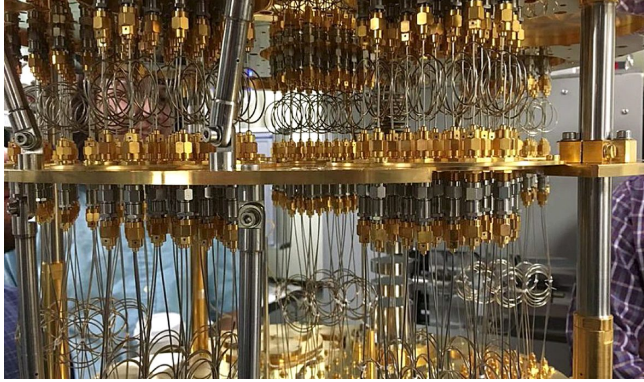
МИЭМ

Московский институт электроники и математики НИУ ВШЭ

Quantum supremacy using a programmable superconducting processor







Резюме

1. **Новая эра –**
NISQ **("noisy intermediate-scale quantum applications"**
by John Preskill, Feinman Professor@Caltech – 02.10.2019)
2. **Сосуществование и взаимо-дополняемость HPC и NISQ**
3. **Поиск классического алгоритма, который повторит результат для 53-х ку-битов?**

Российская Академия Наук

ВЦ РАН

МИЭМ Московский институт электроники и математики НИУ ВШЭ