Zuchongzhi-3 Sets New Benchmark with 105-Qubit Superconducting Quantum Processor

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A team of researchers from the University of Science and Technology of China (USTC) of the Chinese Academy of Sciences (CAS) and its partners have made significant advancements in random quantum circuit sampling with *Zuchongzhi*-3, a superconducting quantum computing prototype featuring 105 qubits and 182 couplers.

Operating at a speed 10^{15} times faster than the most powerful supercomputer currently available and one million times faster than Google's latest published results, the success marks a major milestone in quantum computing ensuing the success of its predecessor, *Zuchongzhi*-2.

The research, led by Prof. PAN Jianwei, a CAS Member, and his USTC colleagues Profs. ZHU Xiaobo and PENG Chengzhi in cooperation with colleagues at home and abroad, has been published as a cover article in *Physical Review Letters* on March 3.

Quantum supremacy, the ability of a quantum computer to perform tasks beyond the reach of classical computers, has been a key goal in the field. In 2019, Google's 53-qubit Sycamore processor completed a random circuit sampling task in 200 seconds, a feat estimated to take 10,000 years on the world's fastest supercomputer at the time. However, in 2023, USTC researchers demonstrated more advanced classical algorithms capable of completing the same task in 14 seconds using over 1,400 A100 GPUs. With the advent of Frontier supercomputers, equipped with expanded memory, this task can now be performed in just 1.6 seconds, effectively challenging Google's earlier claim of quantum supremacy.

Subsequently, using the optimal classical algorithm as its benchmark, the same team at USTC achieved the first rigorously proven quantum supremacy with the *Jiuzhang* photonic quantum computing prototype in 2020. This was followed in 2021 by a superconducting demonstration using the *Zuchongzhi*-2 processor. In 2023, the team's development of the 255-photon *Jiuzhang*-3 demonstrated quantum supremacy that surpassed classical supercomputers by 10^{16} orders of magnitude. In October 2024, Google's 67-qubit superconducting quantum processor, Sycamore, demonstrated quantum supremacy by outperforming classical supercomputers by nine orders of magnitude.

Building upon the 66-qubit *Zuchongzhi*-2, the USTC research team significantly enhanced key performance metrics to develop *Zuchongzhi*-3, which features 105 qubits and 182 couplers. The quantum processor achieves a coherence time of 72 μs, a simultaneous single-qubit gate fidelity of 99.90%, a simultaneous two-qubit gate fidelity of 99.62%, and a simultaneous readout fidelity of 99.13%. The extended coherence time provides the necessary duration for performing more complex operations and computations.

To evaluate its capabilities, the team conducted an 83-qubit,

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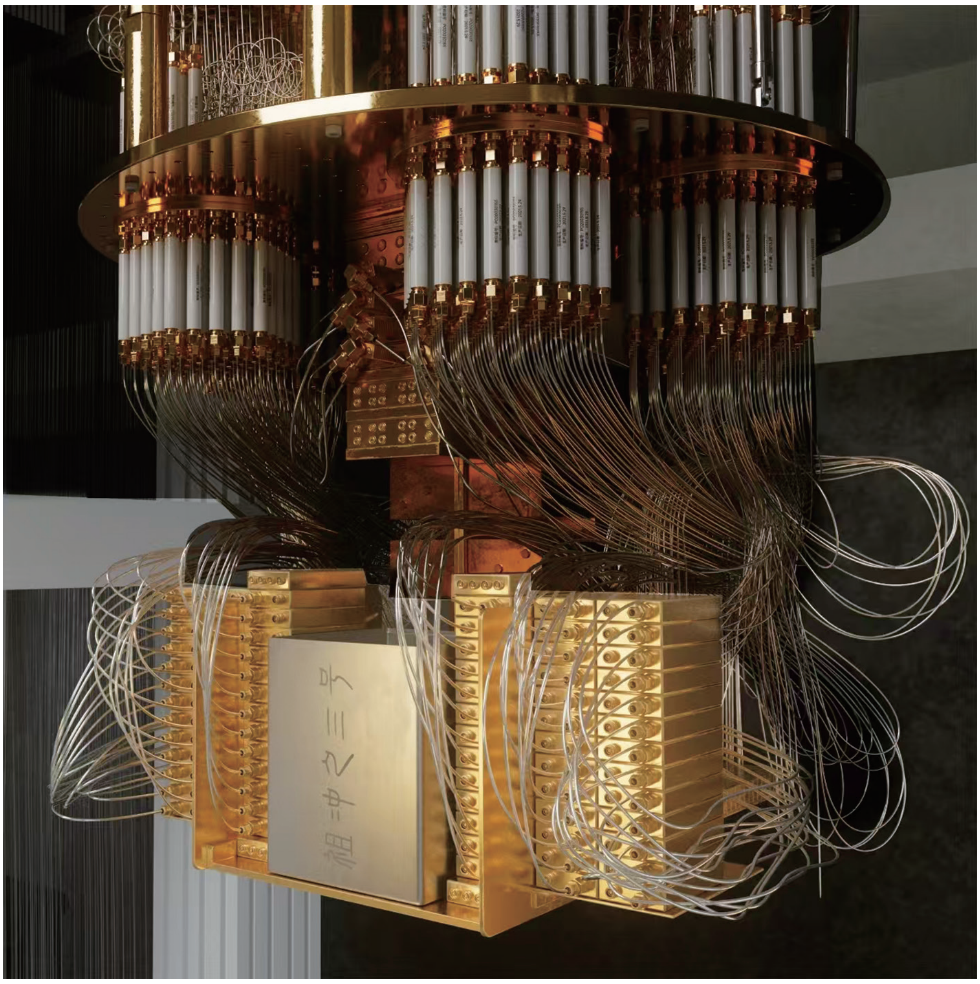

Schematic diagram of the *Zuchongzhi*-3 chip, which integrates 105 qubits and 182 couplers to perform quantum random circuit sampling tasks. (Image by USTC)

32-layer random circuit sampling task on the system. The results demonstrated a computational speed that outpaces the world's most powerful supercomputer by 15 orders of magnitude and surpasses Google's latest quantum computing results by six orders of magnitude, establishing the strongest quantum computational advantage in a superconducting system to date.

Following the achievement of the strongest "quantum computational advantage" with *Zuchongzhi*-3, the team is actively advancing research in quantum error correction, quantum entanglement, quantum simulation, and quantum chemistry. The researchers have implemented a 2D grid qubit architecture, improving qubit interconnectivity and data transfer rates. Utilizing this architecture, they integrated surface code and are currently developing quantum error correction using a distance-7 surface code, with plans to extend this to distances of 9 and 11. These efforts aim to enable large-scale integration and manipulation of quantum bits.

The team's work is profoundly significant and widely acclaimed. One journal reviewer described it as "benchmarking a new superconducting quantum computer, which shows state-of-the-art performance" and a "significant upgrade from the previous 66-qubit device (*Zuchongzhi*-2)." In recognition of the study's critical importance, at the same time, *Physics Magazine* featured a dedicated viewpoint article that provided an in-depth exploration of its innovations and emphasized its broader significance.