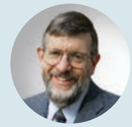
# UMD: UNIQUELY POSITIONED TO LEAD THE NEXT QUANTUM REVOLUTION

"We are witnessing the beginning of a second quantum revolution. The first revolution relied on what is today seen as the 'ordinary' features of quantum theory. The second revolution is based on the truly weird aspects of quantum physics."



Dr. William Phillips
NOBEL LAUREATE AND FELLOW OF THE JOINT QUANTUM INSTITUTE OF THE UNIVERSITY OF MARYLAND AND THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

## WORLD-CHANGING POTENTIAL

The last three centuries have featured defining moments of innovation that changed the course of humankind. Much of the technology that characterized 20th century life resulted from the birth of quantum mechanics. Today, a new age of quantum discovery is emerging.

The University of Maryland is an established world leader in the transformative field of quantum research, putting the weirdness of quantum physics to work in new advances that offer the potential to make an enormous impact on human lives. Researchers capitalize on the strange behavior of quantum systems, which can exist in two different states simultaneously, making new data processing advances possible that supercede the zeros and ones of binary code. The potential impact of quantum research transcends computing.

## DEVELOPING SOLUTIONS FOR CRITICAL SCIENTIFIC CHALLENGES

The complexity of our modern scientific challenges—such as mapping the human brain, advancing personalized medicine and safeguarding communications networks—demands faster processing and greater technological advances. By building a device based on quantum bits, or qubits, it may be possible to store, process and transmit information faster, better and more securely than today's technology.

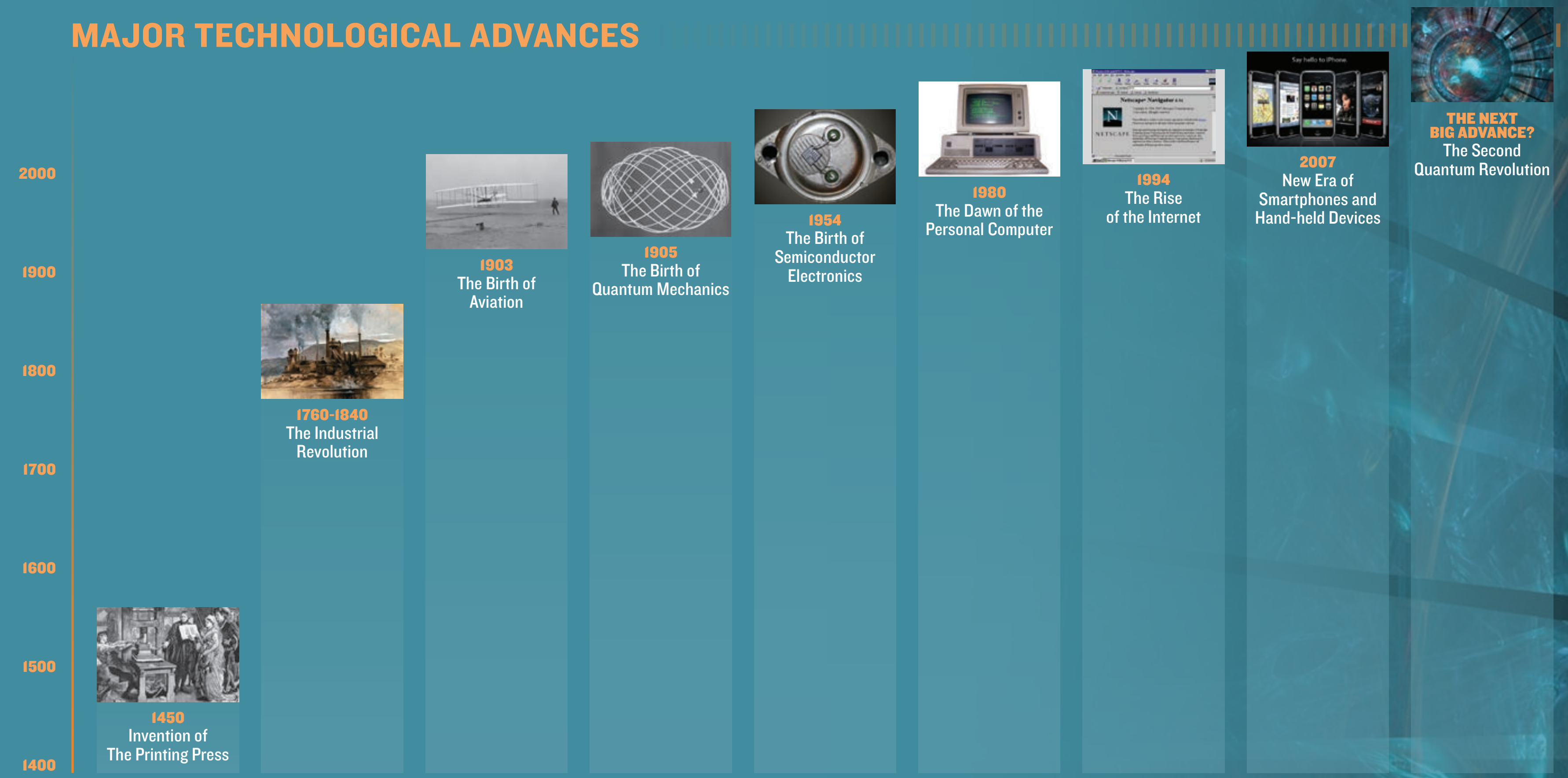
## WHY MARYLAND?

- **World-Renowned Expertise, with nearly 200 Dedicated Researchers**
- **Three Quantum Research Centers Focused on Physics, Computer Science and Engineering**
- **New State of the Art Facility for Quantum Research Activity**
- **Key Location in Washington D.C. Area that Promotes Extensive Collaboration with Federal and Industry Partners**

"Advances in this second wave will not only involve computing, but also sensing and communications. This field has the power to change our world in amazing ways, and the University of Maryland has the research expertise and resources to lead this revolution."

Dr. Patrick O'Shea
UNIVERSITY OF MARYLAND VICE PRESIDENT AND CHIEF RESEARCH OFFICER

## MAJOR TECHNOLOGICAL ADVANCES




UNIVERSITY OF MARYLAND

TO LEARN MORE VISIT
http://research.umd.edu/quantum-research

# THE FUTURE OF QUANTUM RESEARCH BEGINS HERE

UNIVERSITY OF MARYLAND

"The exploration of quantum computing will yield two potential benefits: new algorithms for heretofore unreachable computations and deeper understanding of the mysterious properties of entanglement. The University of Maryland is addressing an important, emerging research field."

Dr. Vint Cerf
VICE PRESIDENT AND CHIEF INTERNET EVANGELIST FOR GOOGLE AND AMERICAN INTERNET PIONEER

### UNIVERSITY OF MARYLAND, COLLEGE PARK

# POISED FOR QUANTUM BREAKTHROUGH

The University of Maryland is a leader in quantum science, with a critical mass of quantum science experts and three research centers focused on different aspects of the field.

UMD offers state-of-the-art facilities, recently opening a new 160,000-square-foot Physical Sciences Complex. The building's innovative design includes extra-thick concrete floors to minimize vibrations that could interfere with experiments, and highly precise temperature control—within a half-degree Fahrenheit.

These are exciting times for advancements in quantum science at Maryland.

"The stars are all aligned. The future is going to be breathtaking," said physicist Jayanth Banavar, dean of the College of Computer, Mathematical, and Natural Sciences (CMNS). "The University of Maryland is going to be able to say that a quantum computer was built here, and that lives were changed because of this."

## THE JOINT QUANTUM INSTITUTE

A great deal of this research is being conducted at the Joint Quantum Institute (JQI), a research partnership between UMD and the National Institute of Standards and Technology (NIST), with support from the Laboratory for Physical Sciences. JQI is led by UMD Professor of Physics **Steven Rolston** and NIST physicist **Charles Clark**. JQI scientists are engaged in major experimental and theoretical research programs dedicated to exploring, controlling and exploiting quantum systems. JQI also hosts a prestigious National Science Foundation Physics Frontier Center, one of only 10 in the nation.

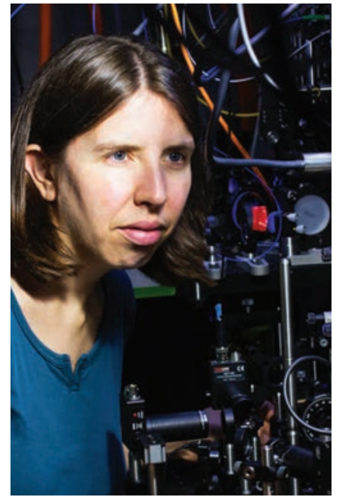
"The information revolution [has been] about using quantum mechanics to understand materials and design devices," said Rolston. "In the last 20 years we have become very good at manipulating individual quantum systems, and we can now exploit some of what we call *quantum weirdness* to do new things."

The breadth of research combined with a synergistic collaborative environment give the institute its strength. JQI research covers atoms, photonics, semiconductors, superconductors and more—all of which have untold potential for discovery.

Many of the institute's scientists are pioneers, like JQI Fellow and atomic physicist **Gretchen Campbell**, who was recognized in 2015 for her work in atomtronics.

"We are really coming to understand quantum mechanics at the macroscopic level," said Richard E. Prange Chair in Physics, Distinguished University Professor, and JQI Fellow **Sankar Das Sarma**. "How do quantum states disappear? What do you have to do to keep quantum states alive forever? How can we see quantum behavior in millions of atoms simultaneously? All of these are big questions that lead to a quantum computer, and they lead to an understanding of nature, too."

VISIT JQI.UMD.EDU



GRETCHEN CAMPBELL, JQI FELLOW

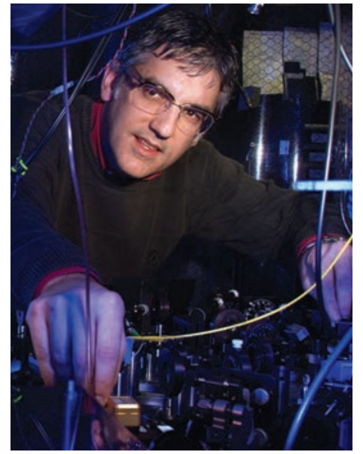
"Harnessing the power of individual atoms to solve some of mankind's most difficult problems is a breathtaking concept. UMD is bursting at the seams with the talent and creativity that will make it happen."

Dr. Michael Wertheimer
FORMER DIRECTOR FOR RESEARCH
NATIONAL SECURITY AGENCY

## THE QUANTUM ENGINEERING CENTER

"Through Lockheed Martin's partnership with the University of Maryland, we hope to capitalize on our shared expertise in quantum science to accelerate innovation and advancements in quantum computing."

Dr. Keoki Jackson
CHIEF TECHNOLOGY OFFICER, LOCKHEED MARTIN



CHRISTOPHER MONROE, QEC DIRECTOR

In March 2014, Lockheed Martin and UMD partnered to create the Quantum Engineering Center (QEC), where researchers are focused on creating a working quantum device. Building on more than 60 years of collaboration between Lockheed Martin and UMD, the QEC seeks to push the boundaries of scientific discovery and innovation.

"This powerful relationship between Lockheed Martin and the University of Maryland represents one of the most historically significant partnerships between a university and a corporation," said **Darryll Pines**, dean of the A. James Clark School of Engineering. "Directing our collaborative focus toward innovation in quantum technology will deliver ground-breaking results."

The initial goal of the Quantum Engineering Center is to demonstrate a quantum platform that features reliable, well-characterized operation without requiring a user to have a deep understanding of the internal workings of the system—just like conventional computers work today. "Lockheed Martin's engineers can take our handcrafted process and turn it into an assembly line, and that's what we need," said QEC Director **Christopher Monroe**, a JQI Fellow, the Bice Zorn Professor of Physics and a world leader in ion trap quantum information. "Our goal is to build a device where you don't have to know its inner workings. You just use it. That requires serious engineering."

In Monroe's lab, physicists use precisely calibrated lasers to trap and control charged atoms—ions—in a vacuum chamber, where they become the processors for the quantum computer. In 2014, his research team used lasers and a specialized camera to characterize a crystal of 18 atom qubits, in a method analogous to MRI for validating experimental protocols. This work was one of the largest demonstrations of its type and was an important bench-marking step in the race to construct machines that can run calculations exponentially faster.

Monroe is confident that quantum computing will eventually become reality. "It will work," he said. "It's a question of time and money."

## THE JOINT CENTER FOR QUANTUM INFORMATION AND COMPUTER SCIENCE



QUICS PARTNERSHIP SIGNING

In addition to the JQI and QEC, the Joint Center for Quantum Information and Computer Science (QuICS) was launched in October 2014. It is a research partnership between the university and NIST, with the support and participation of the Research Directorate of the National Security Agency/Central Security Service, which will focus on quantum information theory. QuICS is led by **Andrew Childs**, a UMD associate professor of computer science, and **Jacob Taylor**, a NIST scientist and JQI Fellow.

QuICS researchers aim to answer questions that fall into four categories: How does our knowledge of quantum mechanics change our understanding of what computers can do? How does our knowledge of quantum computers change our understanding of nature? How can a technological society keep its information secure in a quantum world? And finally, given all the imperfections and challenges of quantum computing, how do we go forward into the second information revolution?

Ongoing projects at QuICS include theoretical and experimental research on quantum algorithms, quantum complexity theory, quantum communication, quantum key distribution, post-quantum cryptography and more. The researchers will think through the possibilities and limitations of a quantum computer that does not yet exist.

The futuristic nature of their work poses certain dilemmas. For example, "If you want to understand the performance of a classical algorithm, you can just run the algorithm and see how it works," said Childs. "Understanding quantum algorithms is harder because we can't yet run them."

QuICS researchers want to understand the kinds of tasks quantum technologies can handle better than conventional ones and what a quantum computer can teach us about the quantum nature of our world. "Exploring that boundary between the two realms is our main focus," said Taylor.

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