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Navigating the Open Oceans of Quantum Synchronicity

LEARNING WHY THE TINIEST PARTICLES SPIN IN PAIRS–AND HOW TO MAKE THEM–HOLDS PROMISE FOR ADVANCED TECHNOLOGIES.

BY LAUREN EMERSON

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IF YOU GO ON A WALK WITH A FRIEND, you might find that, at some point along the way, you've unintentionally begun to walk in sync. Likewise, you may have observed a field of blinking fireflies and noticed that they seem to blink at the same time. Just like friends and fireflies, atoms can synchronize with other atoms, and understanding this phenomenon will shed light on many unanswered questions about quantum mechanics.

University of Oklahoma physics professors Doerte Blume, Grant Biedermann and Alberto Marino are leading a three-year research project to advance our understanding of quantum synchronization, which may have an impact on the future of quantum technologies. The project is led through the OU Homer L. Dodge Department of Physics and Astronomy and the Center for Quantum Research and Technology. Their research is being funded by a $1 million grant from the W. M. Keck Foundation, and its main goal is to develop a quantum network of atoms that will help reveal how collective interactions at the quantum—or smallest measurable—level lead to synchronization.

The project, which aims to address fundamental research questions, has practical implications for network synchronization over fiber optic and wireless channels, like allowing two computers to connect wirelessly over long distances. It may also enable the development of advanced computer chips that can store more information in a smaller amount of space. One thing is for certain: fundamental research and technological advancements go hand in hand, and the team is excited to see where their findings will lead them, Blume says.

Quantum synchronization is exactly what it sounds like: interacting particles will sometimes synchronize their spin and motion. The quantum mechanics—or interaction of matter and light at the atomic level—associated with synchronization aren't fully understood, even when it comes to defining what "synchronization" means at such a small scale.

"What even is synchronization at the quantum level?" reflects Blume, a theorist interested in developing an understanding of quantum mechanical systems. These fundamental questions intrigued her. "How do you define synchronization within the quantum framework? The reason that's not so obvious is that, quantum mechanically, you always have uncertainty. You can't have something at exactly a given spot."

While Blume heads the theoretical branch of the project, Biedermann and Marino provide experimental expertise. Biedermann specializes in implementations of quantum information processing in neutral atom systems, through which atoms have no electrical charge, while Marino specializes in quantum optics—the study of the quantum properties of light and the interaction of quantum light with atoms and molecules. The researchers plan to use cold atoms to create a synchronized quantum network in which the appearance of synchronization in atoms can be studied.

To create a quantum network, the researchers must be able to isolate atoms. Trapping an atom with a laser sounds like something that only happens in science fiction, but it's a reality in physics labs. Tools called "optical tweezers" use tightly focused beams of light to hold a single atom in place. Researchers can then manipulate those atoms. "Now we have the ability to create entangled states between multiple atoms," Biedermann says. "That's all done with these optical tweezers."

Once the atoms in the tweezers are made to oscillate at a specific frequency, researchers propel them to interact with one another through electrostatic forces. This allows the atoms to "feel" each other's motion to some degree and develop synchronization.

Researchers use light to oscillate atoms at the chosen frequency. "The light will introduce forced oscillation," Biedermann says. "It's like taking a pendulum and forcibly swinging it back and forth to make it oscillate at the frequency you determine."

This can be accomplished with a large amount of "normal" light or with a smaller amount of quantum light—specifically "squeezed light." Squeezed light has special properties that relate to quantum entanglement and can more effectively interact with atoms than normal light, Marino says. Essentially, it's better at making the atoms vibrate the way researchers want them to with less uncertainty. Marino has been creating quantum light for more than a decade, and with some small modifications, that light can be applied to the single-atom systems in Biedermann's lab.

"This quantum synchronization project is really coming at the problem from a whole new angle," Biedermann says. "Most of the work people are doing in the realm of quantum control either deals with quantum simulation, or they're approaching it with the goal of building a quantum computer. We're more interested in the dynamics of how quantum information develops, how it evolves and what type of control we actually have."

In the long run, an increased understanding of quantum synchronization and quantum mechanics will be used to develop and refine quantum technologies such as computer chips and fiber-optic links. For now, OU's research team is focused on the crucial steps of establishing the building blocks of quantum synchronization knowledge.

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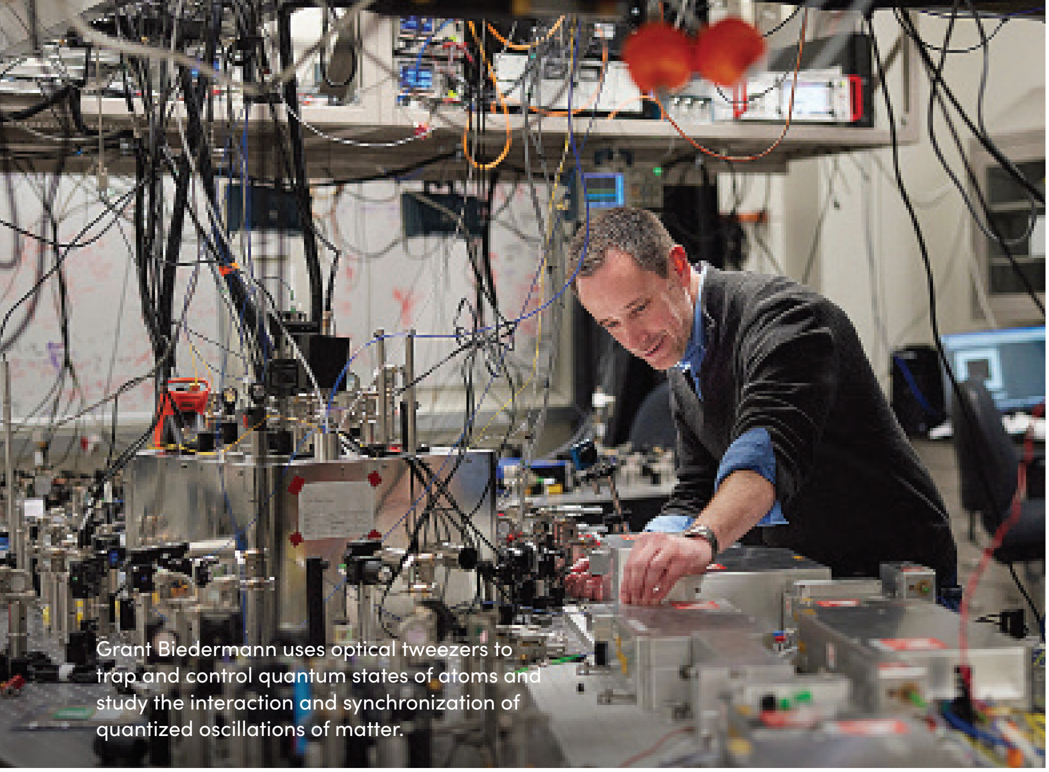
Physics professors Grant Biedermann, left, Doerte Blume and Alberto Marino lead a three-year research project to advance understanding of quantum synchronization.



Grant Biedermann uses optical tweezers to trap and control quantum states of atoms and study the interaction and synchronization of quantized oscillations of matter.

TRAVIS CAPERTON

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"We don't actually have a clean, underlying framework that applies to all systems," Blume says. "We don't have enough theory, insight and experimental data yet. And when I say 'we,' the 'we' is all scientists."

OU has a decades-long history of working with ultra-cold atomic systems, so this project fits perfectly into the greater picture of OU physics research, says Blume. The high-quality lab space at Lin Hall, named for and supported by a major gift from former OU physics faculty member Chun Lin, is perfectly suited for such experiments because its laboratories are designed for sensitive measurements, Blume adds.

Innovative investigations are at the core of what OU research is about. "This kind of basic research into the state of how and why atoms interact is fundamental to paving the way for the revolutionary quantum technologies of the future," says Tomás Díaz de la Rubia, OU's vice president for research and partnerships. "Achieving quantum synchronization will enable a myriad of future technologies—like improved quantum networking—and truly pave the way for an exciting future."

The project wouldn't be possible without student contributions, Blume points out, adding that students also gain experience and the reward of seeing their hard work come to fruition.

"Grant Biedermann, Alberto Marino and I are not doing this on our own," she says. "The majority of the funding is going toward supporting and training graduate students, undergraduate students and postdocs. That's really the core mission of the university."

The team is also building an entirely new research apparatus that is extremely innovative and will serve OU physics research for decades to come, Blume says.

"The apparatus will use an atomic species that has much longer lifetimes. It will allow for unprecedented control that goes way beyond the team's current capabilities, making it easier for different sub-units of the quantum network to interact."

Their work will bring researchers and quantum physicists closer to understanding the mechanisms of quantum synchronization and creating more advanced quantum technologies.

"There's so much information embedded in these quantum information systems that we don't have tried-and-true rules to help guide us to understand what's useful and what's not useful," Biedermann says. "It's uncharted territory. We're still kind of navigating the open oceans here." S

The W. M. Keck Foundation was established in 1954 in Los Angeles by William Myron Keck, founder of The Superior Oil Company. One of the nation's largest philanthropic organizations, the W. M. Keck Foundation supports outstanding science, engineering and medical research.

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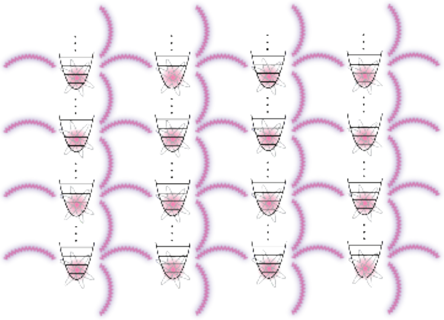

Individual cesium—or strontium atoms—held in optical tweezers, depicted as simple harmonic potentials. The atoms are synchronized, schematically illustrated by curved pink lines.