Researcher discusses trapping single atoms and putting them to work in emerging quantum technologies

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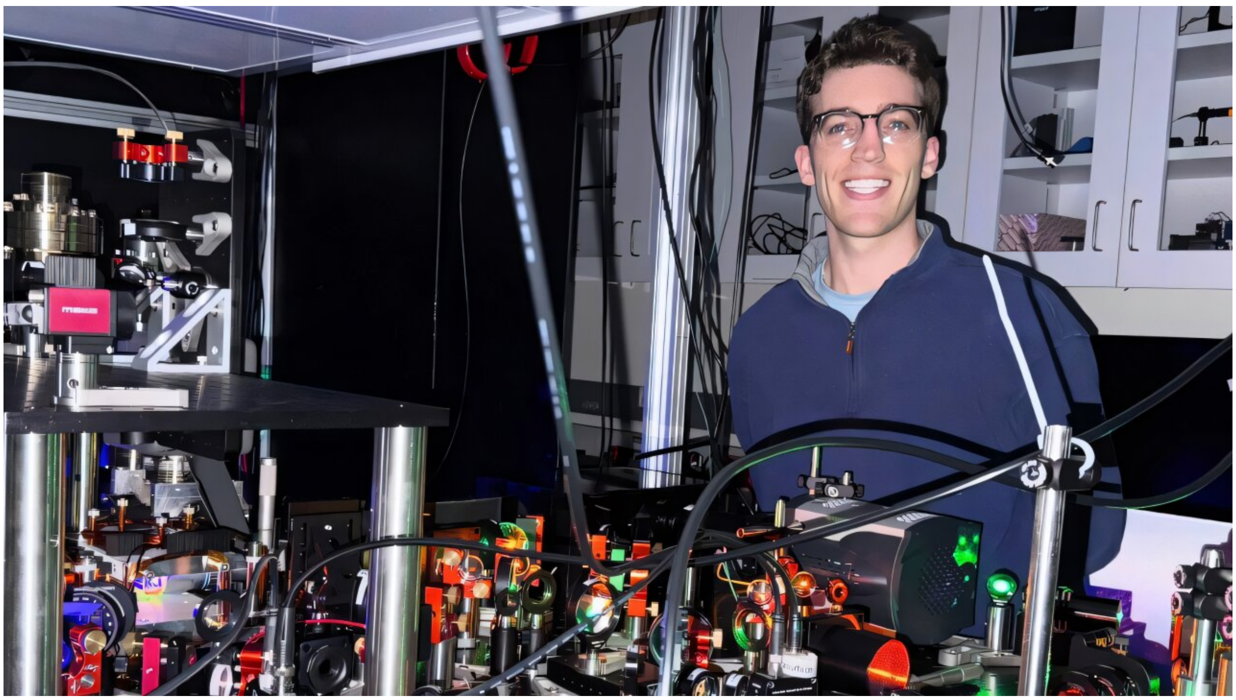

Credit: Columbia University

Blink and you might miss it, but if you keep your eye on the monitors in professor Sebastian Will's lab, you'll catch a series of single-second flashes that light up the screen. Each flash is an atom of strontium, a naturally occurring alkaline-earth metal, being briefly captured and held in place by "tweezers" made of laser light. "We can see single atoms," says graduate student Aaron Holman. "Seeing those never gets old."

The lab saw its first atom at the end of 2022, after two years of constructing the experimental setup—a complicated and carefully calibrated series of atomic sources, vacuum chambers, magnets, electronics, and lasers that trap individual atoms and place them into custom arrangements—from scratch.

Holman, currently a 5th-year Ph.D. student in Physics, helped build the "TweeSr" project, as it's referred to in the lab, from the ground up. A pure atomic, molecular, and optical (AMO) physicist at heart, he's now working on ways to turn fundamental research on how atoms, molecules, and light interact into new technologies with collaborators at Columbia Engineering. He's also heading toward bigger scales as part of a quantum network that is currently under construction.

The network, dubbed SCY-QNet and led by researchers at Stony Brook University, will eventually stretch from Brookhaven National Laboratory on Long Island and through Manhattan by way of Columbia before terminating in New Haven, Connecticut, at Yale.

In this Q&A, Holman explains the "TweeSr" project and how interdisciplinary collaborations make him a better scientist.

How did you come to atomic, molecular, and optical (AMO) physics?

During my undergraduate degree at the University of Chicago, I did a double major in molecular engineering and physics that was very AMO-adjacent: I studied things like quantum networks and materials "doped" with rare-earth ions for use in telecommunications technology. But for graduate school, I decided to switch to pure atomic work. AMO physics is pristine in the sense that we build everything from the ground up. Our systems are exactly what we want them to be.

Can you explain the TweeSr project?

It's a play on "tweezers" combined with the element we work with, strontium. We use a very strong laser that can trap atoms very, very tightly. It's a green laser that can trap atoms within just 520 nanometers. With my fellow grad student, Ximo Sun, and a postdoc in the lab, Bojeong Seo, we've engineered the traps such that we can put one single atom in each tweezer.

We're also collaborating with engineering professor Nanfang Yu's lab. We use their holographic metasurfaces, which are flat optical devices that manipulate light in an extremely precise manner, to create many tweezers from a single laser beam. With the metasurfaces, we can arrange the tweezers in any shape or pattern we want. We can also place single atoms very close together, which is difficult in conventional tweezer experiments.

Because metasurfaces allow us to engineer the atomic system with exact precision, we can study physics that no one has before.

What might come from that new physics?

By placing single atoms close together, we modify how light interacts with them. This collective behavior has not been well explored in systems such as ours. If we arrange atoms in a particular configuration, we can study what's known as superradiance, atoms emitting photons very quickly, or subradiance, atoms emitting photons very slowly. If we think of applications of these phenomena, the former can increase our system's processing bandwidth while the latter can create a new form of quantum memory. Both are exciting prospects for a quantum network!

So the TweeSrs might make their way into New York's quantum network too?

Yes, to have a network, you need to have a start and an end somewhere. The network is going to connect quantum processing units located across all of the participant institutions via quantum entanglement. Columbia is a hardware node: our atoms will send or receive photons within the network while also providing processing power to manipulate that same quantum information. A particularly difficult task is that we need to do this at the single-photon level: there is very little room for error to efficiently connect our system to the network.

That's forcing us to think beyond our own experimental setup. If we want to link our TweeSrs to a fiber that will run out to Long Island, how exactly will we do that? It's also a fun change in scale and perspective. Our experiment takes up a whole room, but now we're talking about laying miles and miles of fiber and data centers connecting different institutions.

What makes the network 'quantum?'

With classical bits, information is binary: it's either a 1 or 0. We have become extremely good at storing, moving, and manipulating this information with classical methods. However, with quantum bits (qubits), which have additional properties such as superposition, coherence, and entanglement, the same technologies developed for classical bits just don't work. It's an open question how exactly we should build a quantum network, one we are attempting to answer through the new collaboration.

Different quantum systems can be good at different tasks related to storing, moving, and manipulating quantum information, which is one argument for why a quantum network is useful. However, we must now solve the challenge of getting disparate quantum systems to talk to one another—not an easy task! That's one of the questions professor Alex Gaeta's lab here at Columbia is working on. They study frequency conversion and how to get two different quantum sources of information to match up.

How do you like all these interdisciplinary efforts?

I'm working on a proper AMO platform, but I have learned so much from interdisciplinary projects. That's shaped me as a researcher and scientist, and it wasn't something I was initially seeking coming into graduate school. For example, the way I, an AMO physicist, think about light is so different from how an optical engineer thinks about it. It's amazing how much you can improve designs with collaborations. They force you to really look around and see what other groups are doing, and how that can inform your own research.

You don't want to be too siloed—what good is it if in 15 or 20 years we have all these well-developed technologies, but none of them interact with each other?

Provided by Columbia University

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