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Using ultracold atoms to find WMDs

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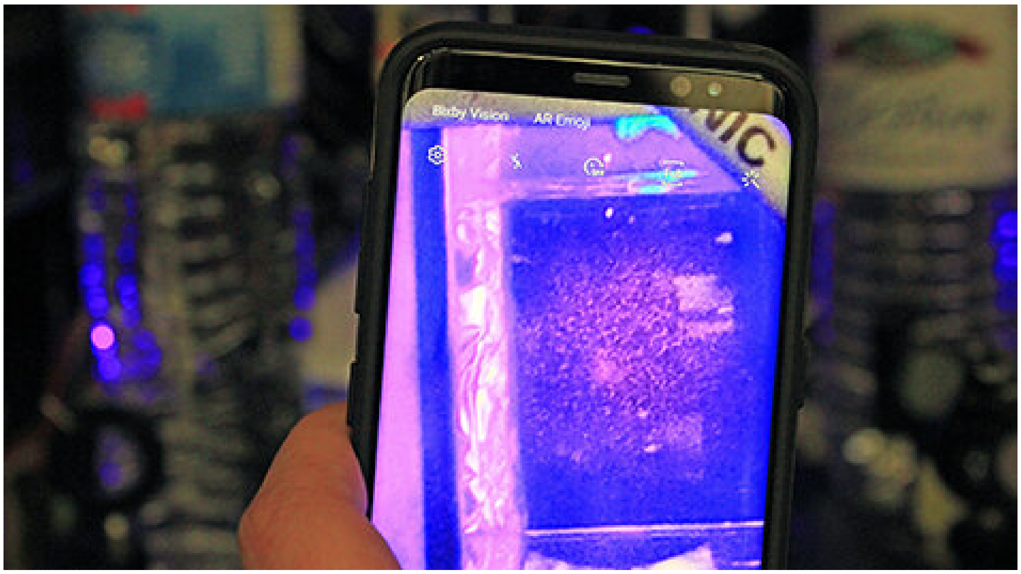


Hi-tech meets low-tech: It takes a low-quality camera to view the high-tech atomic experiments going on inside William & Mary’s Ultracold Atomic, Molecular, and Optical (AMO) Physics Laboratory. This cellphone camera is able to spot a scattering of cooled atoms. Credit: Adrienne Berard

One problem in dealing with weapons of mass destruction is that they are well hidden. The key to finding them may be to change the methods we use to look. One such method is taking shape in a lab in the basement of Small Hall at William & Mary.

"Basically, we're making it so you can see what you can't see," said Seth Aubin, associate professor of physics at William & Mary.

Aubin recently received a grant from the U.S. Department of Defense's Defense Threat Reduction Agency to develop a new type of instrument capable of detecting hidden infrastructure for weapons of mass destruction.

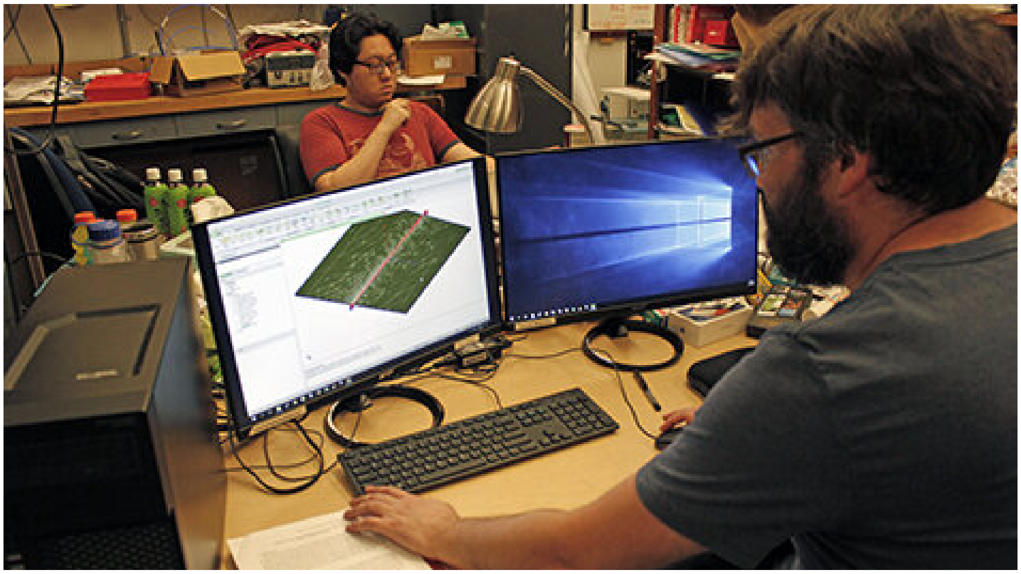
"The agency is particularly interested in finding underground factories or missile silos, things like that," Aubin said, "but you could also use it for spotting submarines or even finding smuggling tunnels and caves."

In order to see the invisible, Aubin says, we first have to reconsider what it means to look. The human eye is designed to process light—or, when you're talking particle physics, photons. When we refer to something as "visible," Aubin explains, it typically means that the photons bouncing off that thing move at a wavelength our eyes can process and therefore see.

But what would happen if we changed our interpretation of "see" to account for something other than light? Aubin aims to do just that: find what's invisible in terms of light, but visible in terms of mass.

Aubin and his team (Bennett Atwater '20, Hantao "Tony" Yu '22, Ph.D. candidates Andrew Rotunno and Shuangli Du, and staff scientist Doug Beringer) are developing a device that uses ultracold atoms to spot distortions in the Earth's gravitational field and "see" using matter instead of light.

"Photons are not that sensitive to gravity," Aubin said. "Things that are sensitive to gravity are things that have mass. The heavier it is, the more sensitive it is and atoms are way heavier than photons."



Seeing the invisible: William & Mary Ph.D. student Shuangli Du (left) and staff scientist Dr. Doug Beringer are part of a team that is developing a device that uses ultracold atoms to spot distortions in the Earth's gravitational field and "see" using matter instead of light. Credit: Adrienne Berard

The idea is to mimic the process of optical interferometry, a precise way of making measurements by monitoring the constructive and destructive interference produced by wavelengths of light. This is how a global team of scientists, including several from William & Mary, were able to detect gravitational waves for the first time, an achievement worthy of the Nobel Prize.

"Basically, you take a light beam and make it go along two paths," Aubin said. "One path will be closer to something and its path will get distorted by gravity. When the beams recombine, you read out the phase difference and it can tell you a lot about what's out there. We're doing the same thing, except with atoms instead of photons."

It makes perfect sense if we leave our comfortable world of Newtonian physics and enter into the realm of quantum mechanics, where mass and energy are interchangeable, and all matter behaves like a wave at the atomic level.

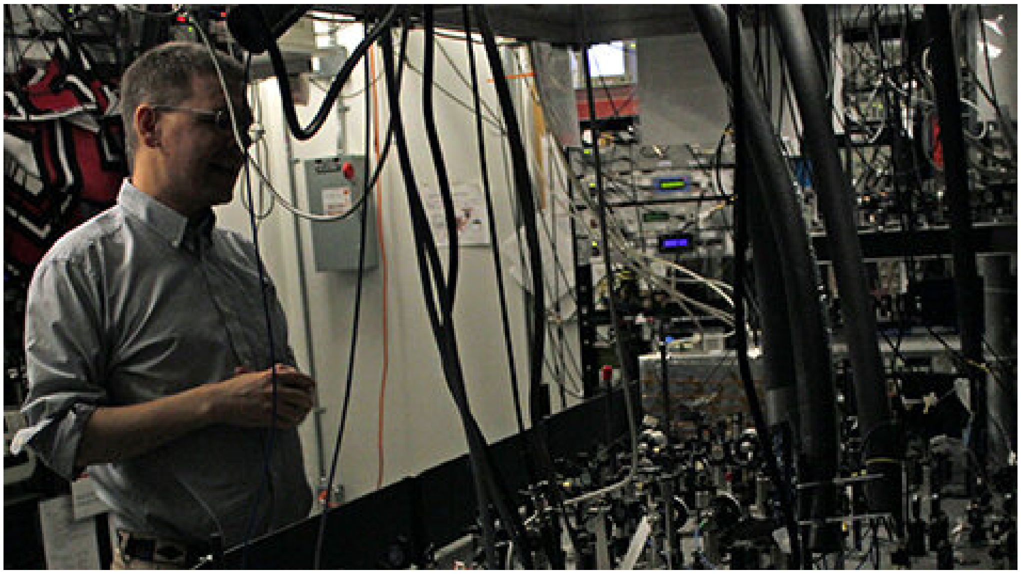
"The idea is to use this method to measure the Earth's gravitational field to an insane precision, let's say part per billion," Aubin said. "That means you're measuring a number that's nine digits long. All the information is in that last digit. That last digit tells you the variation in the gravitational field. What causes it to vary is mass, mass that is missing, like a tunnel or a cave, or mass that's extra, like oil or iron or uranium ore."

It turns out that if you want to get insanely precise, you first have to get insanely cold. The lab uses atoms cooled to about a microkelvin of temperature, nearing absolute zero, the lowest temperature theoretically possible. In fact, the researchers use the coldest object in the universe, the Bose–Einstein condensate, to calibrate their instruments.

"One of the reasons we go so cold is because you don't have to go looking for the quantum mechanics, it comes looking for you," Aubin said. "Matter starts to behave like a wave, whether you like it or not."

Right now, the team is working with super-cold rubidium and potassium atoms, which are cooled using an array of carefully positioned lasers. Nearly half the lab space is dedicated to a table of lenses, mirrors and other optics. They're all oriented to create the perfect laser beam, which is transported to an atom-zapping area via fiberoptic cable.

"When you first look at this, it looks like a gigantic mess," Aubin said, standing beside the optic table. "It is not messy, it's very well organized. For a large fraction of the elements here, if you move them 10 to 100 microns, nothing will work."



It’s all about the optics: Seth Aubin, associate professor of physics at William & Mary, stands in front of a table of lenses, mirrors and other optics that his team uses to manipulate light to cool rubidium and potassium atoms. Credit: Adrienne Berard

Aubin compares laser light photons to snowballs. A snowball is internally cold, but when it's lobbed your way and smacks against your skin, it feels hot. That's because the snowball had a lot of kinetic energy. The photons in laser beams also have a lot of energy, and, like a snowball, are internally cold.

"Laser photons are very energetic, so if you are not clever about how you interact laser light with material, it'll get hot," Aubin said, "but if you are clever about how you interact it, you will actually transfer the coldness of the photons to something else, in this case, our atoms."

Once the atoms are cooled, they are held in a trap before being transferred onto a square-inch microchip, which supports a microwave magnetic field. The field will work to send the atoms along two separate paths before bringing them back together, whereupon the researchers will measure the atomic wavelengths for constructive or destructive interference.

"The chip is where all the physics happens," Aubin said, "but in order to make the physics happen, you need an entire room of equipment."

So far, the team has successfully changed the spin direction of two atoms, but they have yet to send the atoms along two separate paths. A larger-than-expected learning curve may in part be to blame.

"It turns out that microwaves are sort of the dark art of electrical engineering," Aubin said. "It's hard enough that it's not even taught to physicists, so we're teaching ourselves microwave engineering as we go along."

A team of undergraduate students are designing the microwave circuits to power the chip. They have had to do most of the fabrication in-house, Aubin said, gesturing to stacks of electronics scattered around the lab.

"We build most of the stuff that we need," Aubin said. "Typically you can't buy it, because this stuff just doesn't exist. If you're doing something for the first time, you've got to invent your own tools."

Provided by The College of William & Mary

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