# Scientists develop new, faster method for seeking out dark matter

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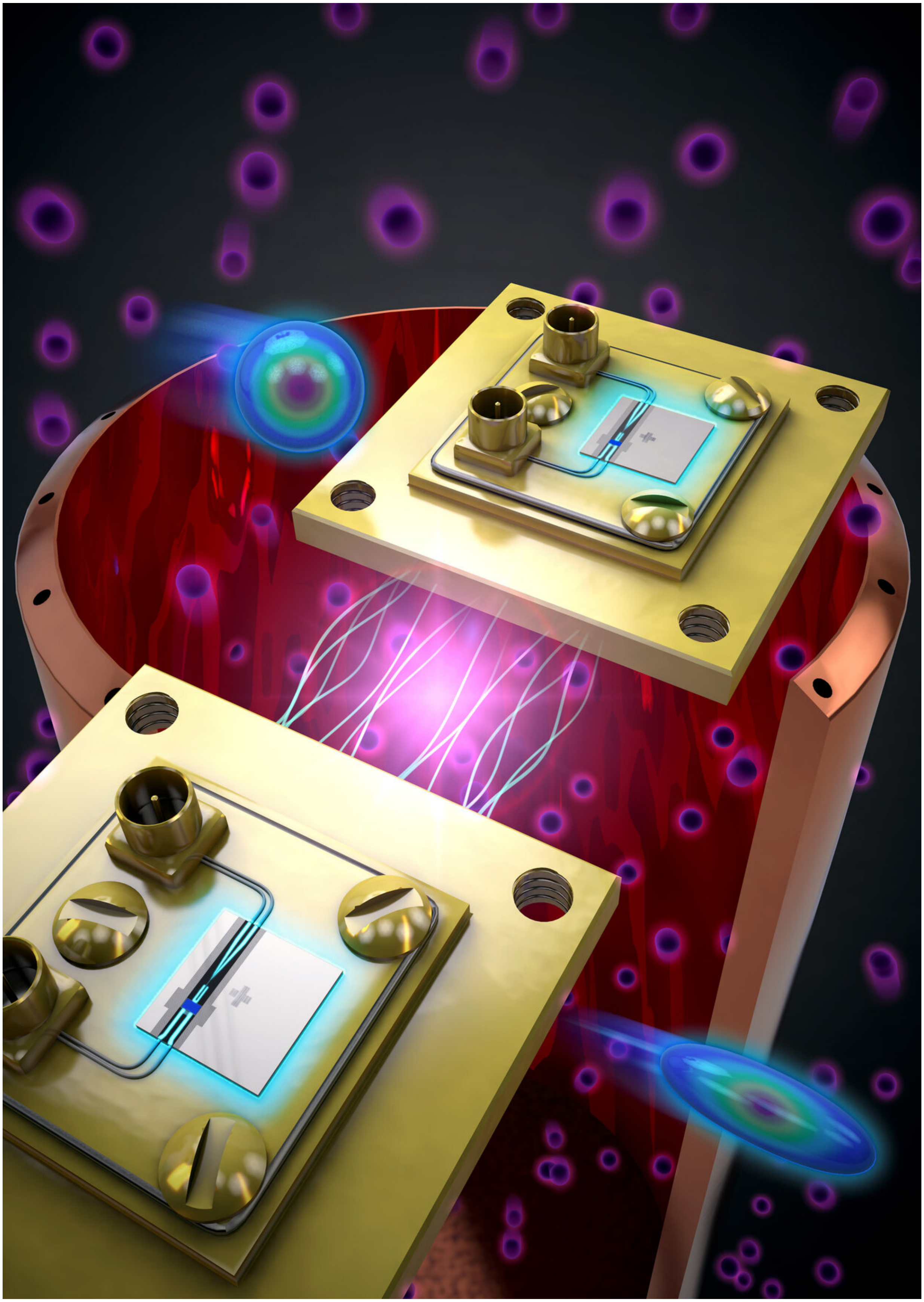

An artist's depiction of the inner workings of the HAYSTAC experiment. Credit: Steven Burrows

For nearly a century, scientists have worked to unravel the mystery of dark matter—an elusive substance that spreads through the universe and likely makes up much of its mass, but has so far proven impossible to detect in experiments. Now, a team of researchers have used an innovative technique called "quantum squeezing" to dramatically speed up the search for one candidate for dark matter in the lab.

The findings, published today in the journal *Nature*, center on an incredibly lightweight and as-of-yet undiscovered particle called the axion. According to theory, axions are likely billions to trillions of times smaller than electrons and may have been created during the Big Bang in humungous numbers—enough to potentially explain the existence of dark matter.

Finding this promising particle, however, is a bit like looking for a single quantum needle in one really big haystack.

There may be some relief in sight. Researchers on a project called, fittingly, the Haloscope At Yale Sensitive To Axion Cold Dark Matter (HAYSTAC) experiment report that they've improved the efficiency of their hunt past a fundamental obstacle imposed by the laws of thermodynamics. The group includes scientists at JILA, a joint research institute of the University of Colorado Boulder and the National Institute of Standards and Technology (NIST).

"It's a doubling of the speed from what we were able to do before," said

Kelly Backes, one of two lead authors of the new paper and a graduate student at Yale University.

The new approach allows researchers to better separate the incredibly faint signals of possible axions from the random noise that exists at extremely small scales in nature, sometimes called "quantum fluctuations." The team's chances of finding the axion over the next several years are still about as likely as winning the lottery, said study coauthor Konrad Lehnert, a NIST Fellow at JILA. But those odds are only going to get better.

"Once you have a way around quantum fluctuations, your path can just be made better and better," said Lehnert, also a professor adjoint in the Department of Physics at CU Boulder.

HAYSTAC is led by Yale and is a partnership with JILA and the University of California, Berkeley.

## Quantum laws

Daniel Palken, the co-first author of the new paper, explained that what makes the axion so difficult to find is also what makes it such an ideal candidate for dark matter—it's lightweight, carries no electric charge and almost never interacts with normal matter.

"They don't have any of the properties that make a particle easy to detect," said Palken, who earned his Ph.D. from JILA in 2020

But there's one silver lining: If axions pass through a strong enough magnetic field, a small number of them may transform into waves of light—and that's something that scientists can detect. Researchers have launched efforts to find those signals in powerful magnetic fields in space. The HAYSTAC experiment, however, is keeping its feet planted on Earth.

The project, which published its first findings in 2017, employs an ultra-cold facility on the Yale campus to create strong magnetic fields, then try to detect the signal of axions turning into light. It's not an easy search. Scientists have predicted that axions could exhibit an extremely wide range of theoretical masses, each of which would produce a signal at a different frequency of light in an experiment like HAYSTAC. In order to find the real particle, then, the team may have to rifle through a large range of possibilities—like tuning a radio to find a single, faint station.

"If you're trying to drill down to these really feeble signals, it could end up taking you thousands of years," Palken said.

Some of the biggest obstacles facing the team are the laws of quantum mechanics themselves—namely, the Heisenberg Uncertainty Principle, which limits how accurate scientists can be in their observations of particles. In this case, the team can't accurately measure two different properties of the light produced by axions at the same time.

The HAYSTAC team, however, has landed on a way to slip past those immutable laws.

## Shifting uncertainties

The trick comes down to using a tool called a Josephson parametric amplifier. Scientists at JILA developed a way to use these small devices to "squeeze" the light they were getting from the HAYSTAC experiment.

Palken explained that the HAYSTAC team doesn't need to detect both properties of incoming light waves with precision—just one of them. Squeezing takes advantage of that by shifting uncertainties in measurements from one of those variables to another.

"Squeezing is just our way of manipulating the quantum mechanical vacuum to put ourselves in a position to measure one variable very well," Palken said. "If we tried to measure the other variable, we would find we would have very little precision."

To test out the method, the researchers did a trial run at Yale to look for the particle over a certain range of masses. They didn't find it, but the experiment took half the time that it usually would, Backes said.

"We did a 100-day data run," she said. "Normally, this paper would have taken us 200 days to complete, so we saved a third of a year, which is pretty incredible."

Lehnert added that the group is eager to push those bounds even farther—coming up with new ways to dig for that ever-elusive needle.

"There's a lot of meat left on the bone in just making the idea work better," he said.

**More information:** A quantum enhanced search for dark matter axions, *Nature* (2021). DOI: 10.1038/s41586-021-03226-7 , www.nature.com/articles/s41586-021-03226-7

Provided by University of Colorado at Boulder

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