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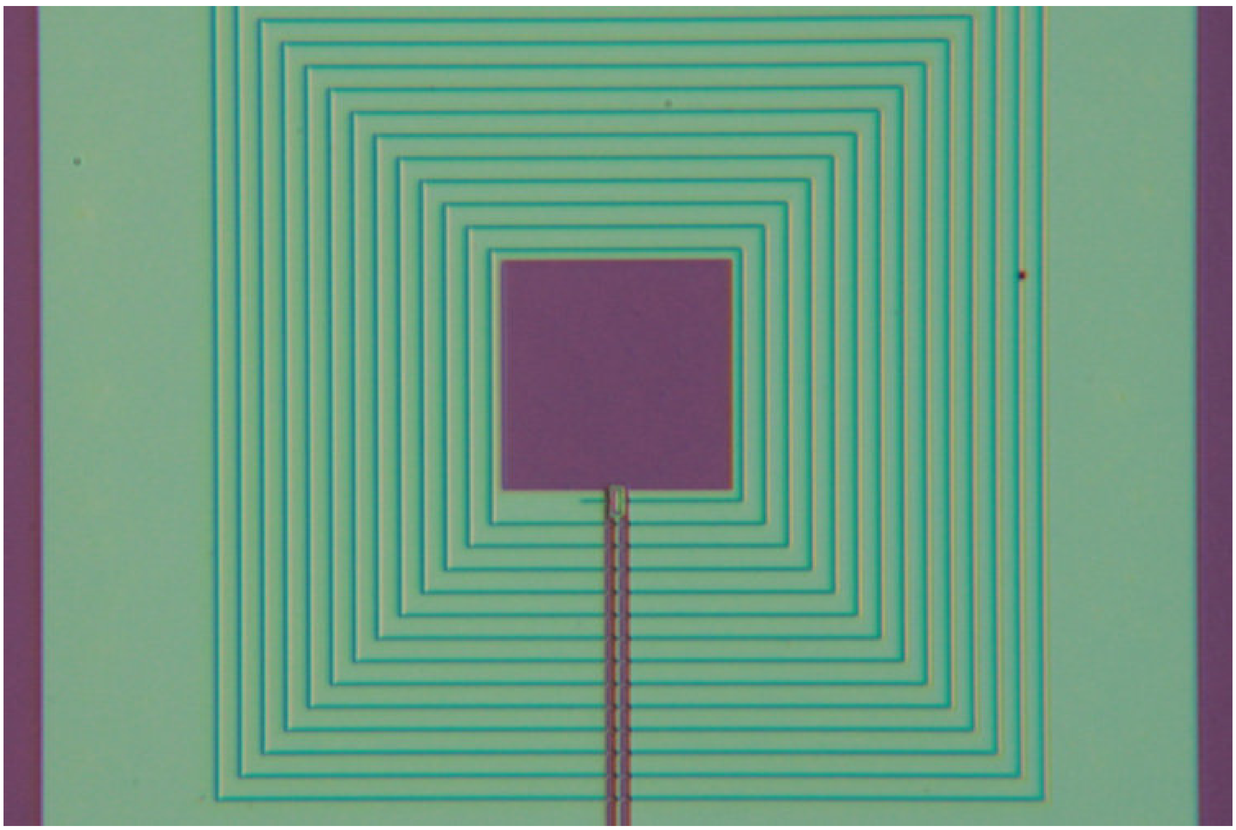
Start of most sensitive search yet for dark matter axion

April 10 2018, by Robert Sanders



The SQUID-based amplifier, which is about a millimeter square, is supercooled to be sensitive to faint signals from axions, should they convert into a microwave photon in the ADMX detector. Credit: Sean O'Kelley image

Thanks to low-noise superconducting quantum amplifiers invented at the

University of California, Berkeley, physicists are now embarking on the most sensitive search yet for axions, one of today's top candidates for dark matter.

The Axion Dark Matter Experiment (ADMX) reported results today showing that it is the world's first and only experiment to have achieved the necessary sensitivity to "hear" the telltale signs of dark matter axions.

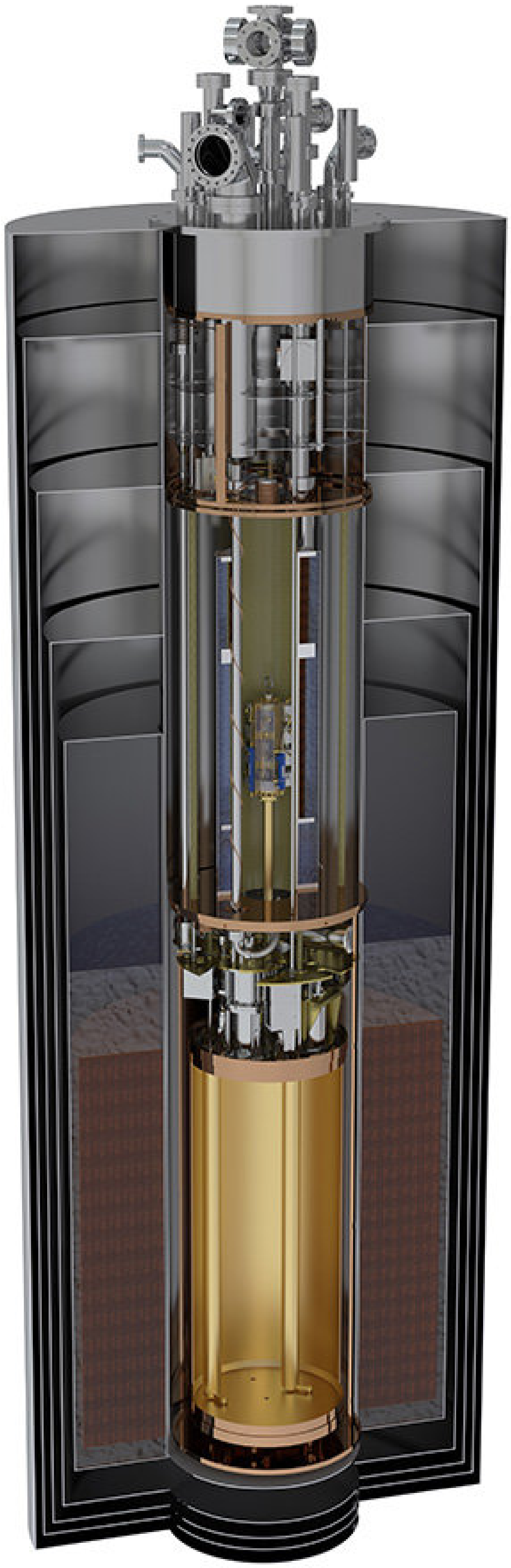
The milestone is the result of more than 30 years of research and development, with the latest piece of the puzzle coming in the form of a quantum device that allows ADMX to listen for axions more closely than any experiment ever built.

John Clarke, a professor of physics in the graduate school at UC Berkeley and a pioneer in the development of sensitive magnetic detectors called SQUIDs (superconducting quantum interference devices), developed the amplifier two decades ago. ADMX scientists, with Clarke's input, have now incorporated it into the ADMX detector at the University of Washington, Seattle, and are ready to roll.

"ADMX is a complicated and quite expensive piece of machinery, so it took a while to build a suitable detector so that they could put the SQUID amplifier on it and demonstrate that it worked as advertised. Which it did," Clarke said.

The ADMX team published their results online today in the journal *Physical Review Letters*.

"This result signals the start of the true hunt for axions," said Andrew Sonnenschein at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, the operations manager for ADMX. "If dark matter axions exist within the frequency band we will be probing for the next few years, then it's only a matter of time before we find them."



A cutaway rendering of the ADMX detector, which can detect axions producing photons within its cold, dark interior. Credit: ADMX collaboration

Dark matter: MACHOs, WIMPs or axions?

Dark matter is the missing 84 percent of matter in the universe, and physicists have looked extensively for many possible candidates, most prominently massive compact halo objects, or MACHOs, and weakly interacting massive particles, or WIMPs. Despite decades of searching for MACHOs and WIMPs, scientists have struck out; they can see the effects of dark matter in the universe, in how galaxies and stars within galaxies move, but they can't see dark matter itself.

Axions are becoming the favored alternative, in part because their existence would also solve problems with the standard model of particle physics today, including the fact that the neutron should have an electric dipole moment, but doesn't.

Like other dark-matter candidates, axions are everywhere but difficult to detect. Because they interact with ordinary matter so rarely, they stream through space, even passing through the Earth, without "touching" ordinary matter. ADMX employs a strong magnetic field and a tuned, reflective box to encourage axions to convert to microwave-frequency photons, and uses the quantum amplifier to "listen" for them. All this is done at the lowest possible temperature to reduce background noise.

Clarke learned of a key stumbling block for ADMX in 1994, when meeting with physicist Leslie Rosenberg, now a professor at the University of Washington and chief scientist for ADMX, and Karl van

Bibber, now chair of UC Berkeley's Department of Nuclear Engineering. Because the axion signal would be very faint, any detector would have to be very cold and "quiet." Noise from heat, or thermal radiation, is easy to eliminate by cooling the detector down to 0.1 Kelvin, or roughly 460 degrees below zero Fahrenheit. But eliminating the noise from standard semiconductor transistor amplifiers proved difficult.

They asked Clarke, would SQUID amplifiers solve this problem?

Supercold amplifiers lower noise to absolute limit

Though he had built SQUID amplifiers that worked up to 100 MHz frequencies, none worked at the gigahertz frequencies needed, so he set to work to build one. By 1998, he and his collaborators had solved the problem, thanks in large part to initial funding from the National Science Foundation and subsequent funding from the Department of Energy (DOE) through Lawrence Berkeley National Laboratory. The amplifiers on ADMX were funded by DOE through the University of Washington.

Clarke and his group showed that, cooled to temperatures of tens of milliKelvin above absolute zero, the Microstrip SQUID Amplifier (MSA) could achieve a noise that was quantum limited, that is, limited only by Heisenberg's Uncertainty Principle.

"You can't do better than that," Clarke said.

This much quieter technology, combined with the refrigeration unit, reduced the noise by a factor of about 30 at 600 MHz so that a signal from the axion, if there is one, should come through loud and clear. The MSA currently in operation on ADMX was fabricated by Gene Hilton at the National Institute of Standards and Technology in Boulder, Colorado, and tested, calibrated and packaged by Sean O'Kelley, a graduate student in Clarke's research group at UC Berkeley.

The ADMX team plans to slowly tune through millions of frequencies in hopes of hearing a clear tone from photons produced by axion decay.

"This result plants a flag," said Rosenberg. "It tells the world that we have the sensitivity, and have a very good shot at finding the axion. No new technology is needed. We don't need a miracle anymore, we just need the time."

Clarke noted too that the high-frequency, low-noise quantum SQUID amplifiers he invented for ADMX have since been employed in another hot area of physics, to read out the superconducting quantum bits, or qubits, for quantum computers of the future.

More information: N. Du et al. Search for Invisible Axion Dark Matter with the Axion Dark Matter Experiment, *Physical Review Letters* (2018). DOI: 10.1103/PhysRevLett.120.151301

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