Searching for invisible axion dark matter with a new multiple-cell cavity haloscope

December 28 2020, by Ingrid Fadelli

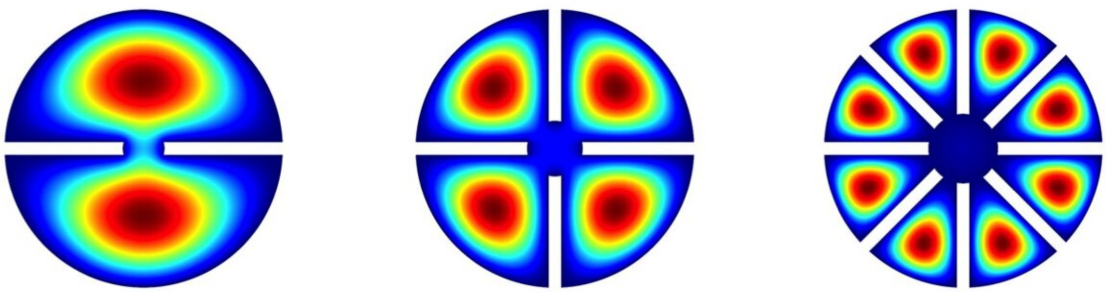

Figure showing the cross-sectional view of various multiple-cell (double-, quadruple-, and octuple-cell) cavities with the expected distribution of the axion-induced electric field by the resonant mode of interest. Credit: Jeong et al.

Over the past few decades, many experimental physicists have been probing the existence of particles called axions, which would result from a specific mechanism that they think could explain the contradiction between theories and experiments describing a fundamental symmetry. This symmetry is associated with a matter-antimatter imbalance in the Universe, reflected in interactions between different particles.

If this mechanism took place in the early Universe, such a particle might have a very small mass and be 'invisible." Subsequently, researchers proposed that the axion might also be a promising candidate for dark matter, an elusive, hypothetical type of matter that does not emit, reflect or absorb light.

While dark matter has not yet been experimentally observed, it is believed to make up 85% of universe's mass. Detecting axions could have important implications for ongoing dark matter experiments, as it could enhance the present understanding of these elusive particles.

Researchers at the Institute for Basic Science (IBS) have recently carried out a search for invisible axion dark matter using a multiple-cell cavity haloscope that they designed (i.e., an instrument to observe halos, parhelia, and other similar physical phenomena). Their results compared favorably to those of previous haloscope-based axion dark matter searches, highlighting the potential of the instrument they created for both dark matter searches and other physics research.

"The axion is detectable in the form of a microwave photon that it is converted into in the presence of a strong magnetic field," SungWoo Youn, one of the researchers who carried out the study, told Phys.org. "A cavity haloscope, typically employing a cylindrical resonator placed in a solenoid to utilize resonance to enhance the signal, is the most sensitive approach to probe the well-established theoretical models."

While cavity haloscopes could be promising tools for detecting axions, they are generally very sensitive to relatively low frequencies. This is mainly because resonant frequencies are inversely proportional to the cavity's radius, which reduces the detection volume for high-frequency searches.

This is one of the reasons why the most sensitive axion search carried out so far, namely the Axion Dark Matter eXperiment (ADMC) by the University of Washington, set experimental limits below 1GHz. One of the possible ways to avoid this volume loss would be to bundle many smaller cavities together and combine individual signals, to ensure that all frequencies and phases are synchronized.

"This multiple-cavity system has been proposed earlier, but has not been successfully addressed, due to effects on the reliability and increased complexity of the system's operation," Youn said. "Our team at the Center for Axion and Precision Physics Research (CAPP) at IBS, located at the Korea Advanced Institute of Science and Technology (KAIST) in South Korea, led by myself, thus developed a novel cavity design, so-called multiple-cell cavity."

The cavity haloscope designed by Youn and his colleagues is characterized by multiple partitions that vertically divide the volume of its cavity into identical cells. This unique design increases resonant frequencies with a minimal loss in volume. The researchers also ensured that partitions situated in the middle of the cavity are separated by a gap.

"By making all the cells spatially connected, our design enables a single antenna to pick up the signal from the entire volume and thus significantly simplifies the structure of the receiver chain," Youn explained. "The optimally sized gap also allows the axion-induced signal to be evenly distributed over the space, which maximizes the effective volume regardless of machining tolerance and mechenical misalighment in cavity construction. I dubbed this cavity design 'pizza cavity' and compared the gap to a pizza saver, which keeps slices intact with its original toppings."

The haloscope that the researchers used to conduct their experiment is the result of approximately two years of research based on simulations, followed by the fabrication of numerous prototypes. In their recent study, it was used to perform a search for axion dark matter utilizing a 9T-superconducting magnet at a temperature of 2 kelvin (−271 °C). This allowed the researchers to quickly scan a frequency range of >200 MHz above 3 GHz, which is 4~5 times higher than that covered by the ADMX experiment.

"Even if we have not observed any axion-like signal, we successfully demonstrated that the multiple-cell cavity would be able to detect high frequency signals with high performance and reliability," Youn said. "We also calculated that due to the larger volume and higher efficiency, this new cavity design can enable us to explore the given frequency range 4 times faster than the conventional one. I often make a humorous but meaningful statement: "If a traditional experiment takes 4 years to probe something, our experiment will take only 1 year. Our Ph.D. students can graduate a lot faster than others.'"

The study carried out by Youn and his colleagues proves the value and potential of the pizza-cavity haloscope they developed for conducting invisible dark matter searches in high-frequency regions. In the future, it could thus aid the search for this elusive type of matter and someday perhaps even enable its detection.

"Currently, our center is also preparing for experiments by grafting several pizza cavities onto the existing systems to search for even higher-frequency axions," Youn added.

More information: Search for invisible axion dark matter with a multiple-cell haloscope. *Physical Review Letters*(2020). DOI: 10.1103/PhysRevLett.125.221302.