South Korea debuts first search for DFSZ axion dark matter

February 20 2023

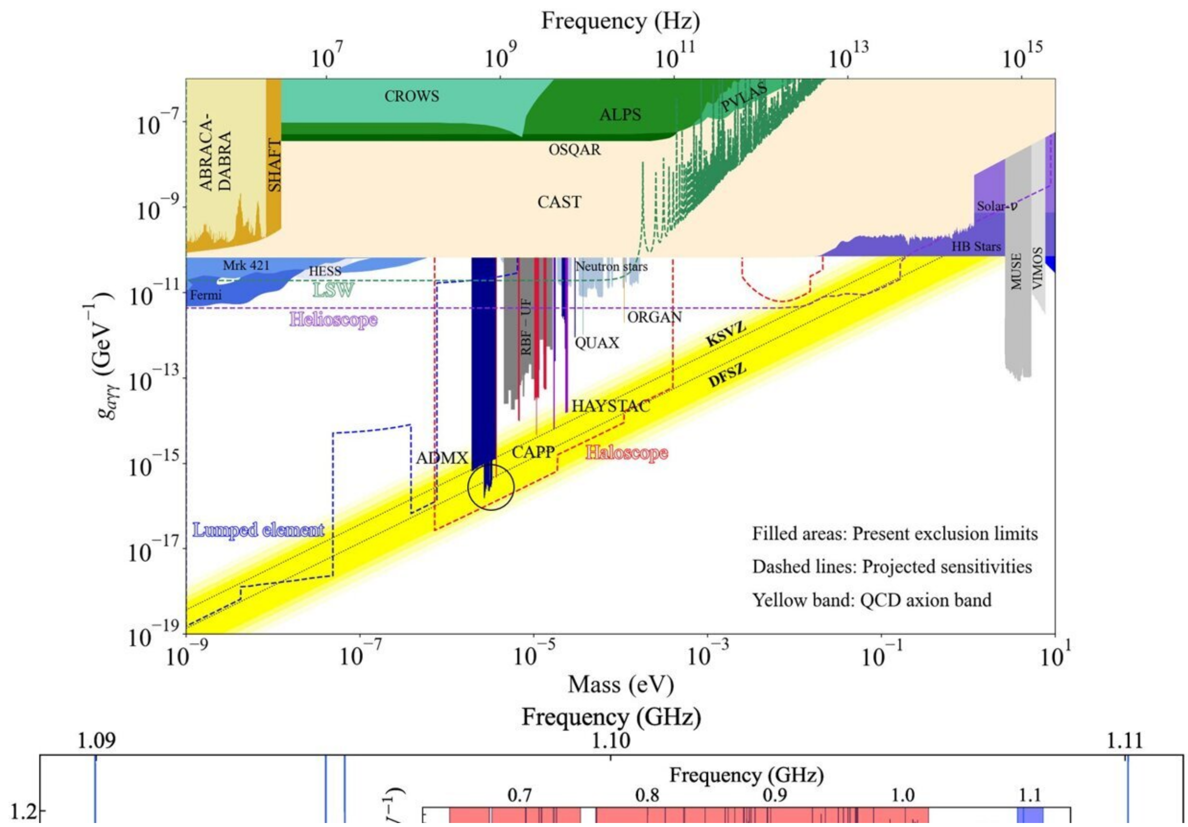

Figure 1. (Top) Current exclusion limits for axion mass from both experiments and astrophysical observation. KSVZ line is the expectation for standard KSVZ axion, while DFSZ line is GUT DFSZ axion. Searching for DFSZ axions requires much higher sensitivity than KSVZ axions. IBS-CAPP axion search experiment explored axion dark matter around 1.1 GHz frequency range at DFSZ sensitivity, denoted by red. Blue denotes the ranges previously excluded by ADMX.(Bottom) IBS-CAPP axion search experiment explored axion dark matter around 1.1 GHz frequency range at DFSZ sensitivity, denoted by blue.

Red denotes the axion search experiment previously conducted by ADMX. Credit: Institute for Basic Science

A South Korean research team at the Center for Axion and Precision Physics Research (CAPP) within the Institute for Basic Science (IBS) recently announced the most advanced experimental setup to search for axions. The group has successfully taken its first step toward the search for Dine-Fischler-Srednicki-Zhitnitsky (DFSZ) axion dark matter originating from the Grand Unification Theory (GUT). Not only that, the IBS-CAPP experimental setup allows for far greater search speed compared to any other axion search experiments in the world.

The notion of physics being "dead" has been a recurrent opinion across history. In the late 19th century, William Thompson, also known as Lord Kelvin, erroneously believed that there would be no new discovery in physics after 1900. Likewise, some have thought that there were no new particles to be found after neutrons were discovered in the 1930s. Even today, some worry that modern theoretical physics is at a dead end.

However, this is far from the truth. Our current limit of knowledge in physics, the Standard Model, is capable of only explaining about 5% of the universe, with the other 95% consisting of dark matter and dark energy.

The current Standard Model also has limitations in explaining problems such as the strong CP (charge conjugation-parity) problem. The problem arises from the observation that the strong force, which is described by quantum chromodynamics (QCD), does not appear to violate CP symmetry, while the electroweak force violates CP symmetry to a small extent. This contradicts the Standard Model, which predicts that CP symmetry should be violated by the strong force at a level that is much larger than what has been observed.

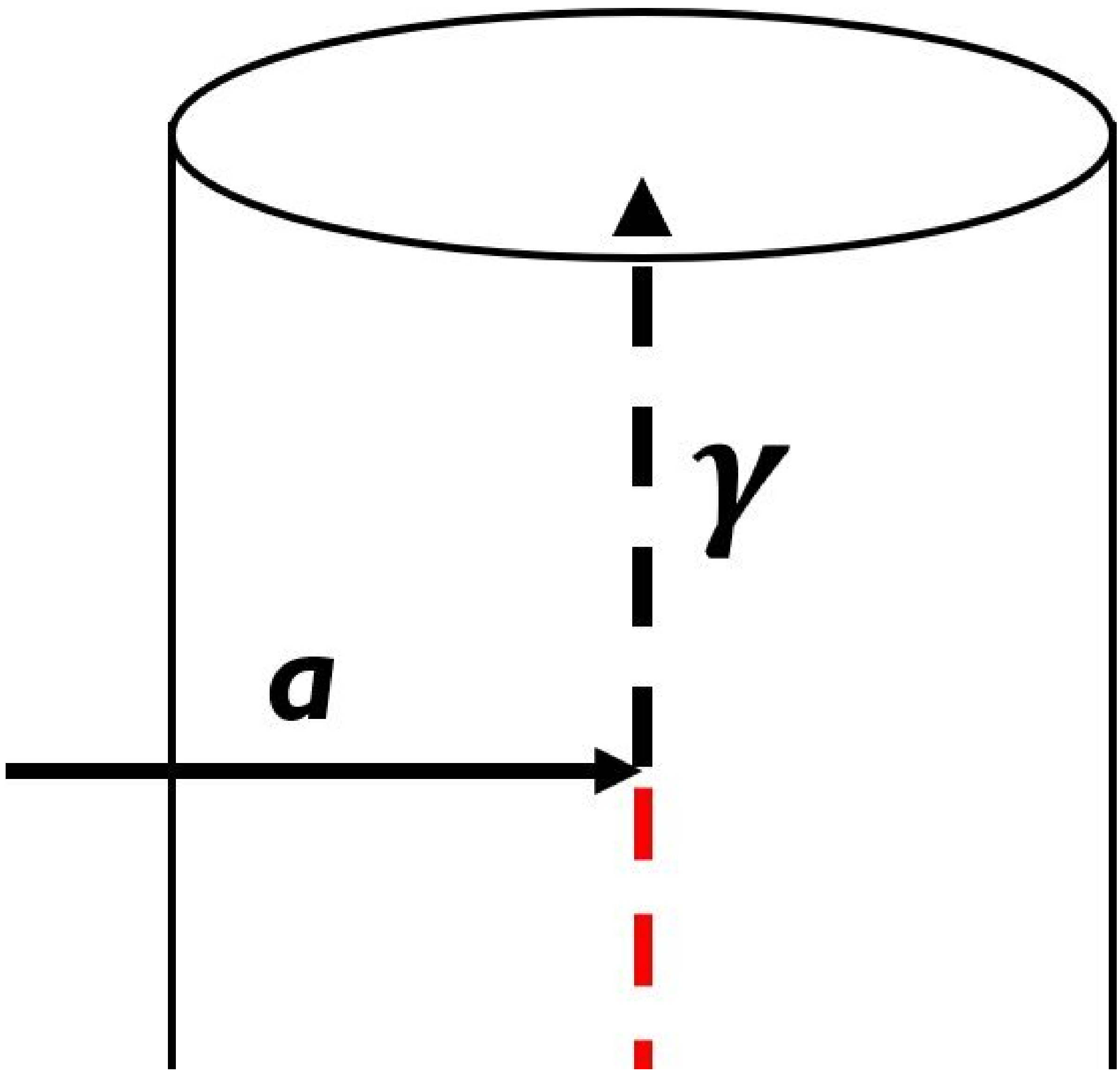

Figure 2. Interaction among halo axions around us (a), magnetic field (B0), and photon (γ). γ is the observable in the experiment and corresponds to the axion signal. The cylinder denotes a microwave resonant cavity. Credit: Institute for Basic Science

One proposed solution to the problem involves the existence of hypothetical particles called axions, which could resolve the discrepancy between the predicted and observed levels of CP violation in the strong force. The axion is one of the strongest candidates for dark matter. The discovery of axion dark matter would undoubtedly be a landmark event in human history.

Currently, two different proposals for "beyond the Standard Model" exist to explain the strong CP problem. The main difference between the two models is that they predict different types of couplings between axions and other particles. In the Kim-Shifman-Vainshtein-Zakharov (KSVZ) model, axions are primarily coupled to heavy quarks, while in the Dine-Fischler-Srednicki-Zhitnitsky (DFSZ) model, they are coupled to the Standard Model quarks and leptons via Higgs bosons.

As dark matter, axions have very weak (or little) interaction with ordinary matter, so searching for them can be a tricky business. One commonly used approach involves microwave cavity experiments. These experiments use a strong magnetic field to convert axions (if they exist) into resonant electromagnetic waves, which are then detected using a receiver. The axion's mass can then be calculated from the detected wave's frequency.

Since axion mass is unknown, physicists must expand their search and scan a huge range of frequencies.

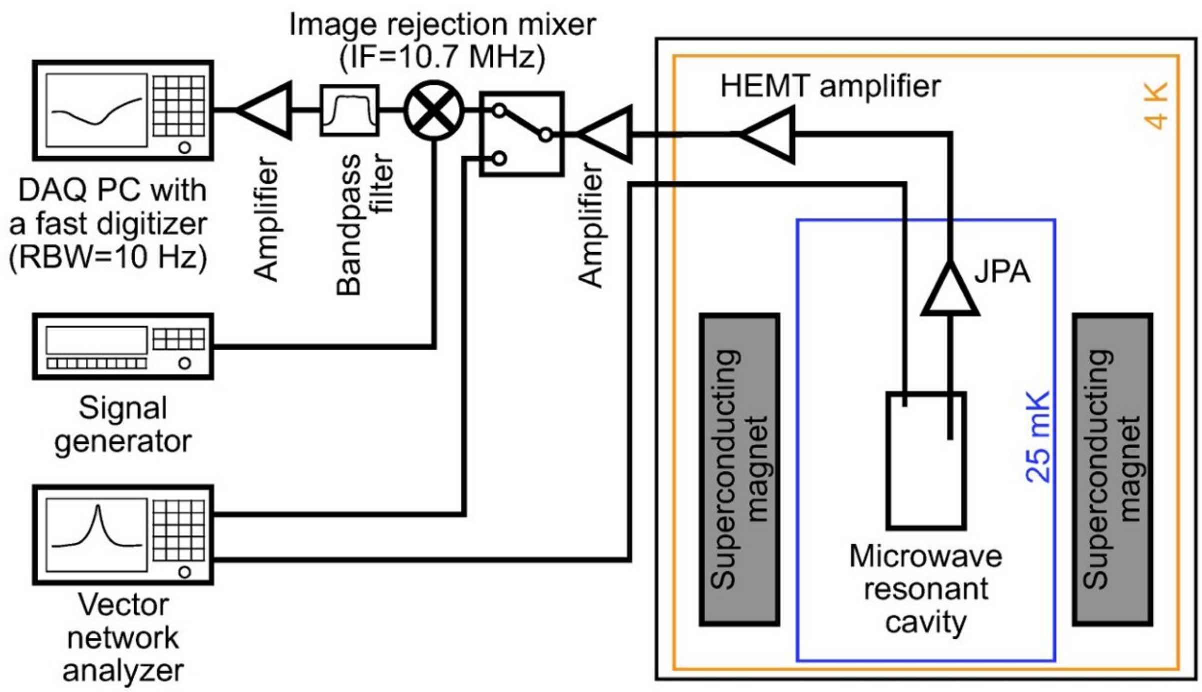

Figure 3. Schematic of the CAPP-12TB experiment. Credit: Institute for Basic Science

The problem is exacerbated in the case of searching for a DFSZ axion, which requires much greater sensitivity than the KSVZ axion. In microwave cavity search experiments, achieving higher sensitivity requires exponentially higher search time, and hence searching for a DFSZ axion is out of reach for almost all existing experimental setups.

As a result, while a few axion search experiments have successfully searched for signals in the KSVZ axion sensitivity ranges, so far the only experiment that was capable of attaining the sensitivity necessary to search for DFSZ axions was the ADMX (Axion Dark Matter eXperiment) conducted by the ADMX collaboration. This makes IBS-CAPP the second group in the world to successfully search for axion with DFSZ sensitivity.

IBS-CAPP group utilized a 12T magnet, which is more powerful than the 8T magnet used by the ADMX. In order to minimize the background noise, the experiment setup was maintained at close to absolute zero temperature.

In addition to using a more powerful magnet, the IBS-CAPP experiment used quantum technologies and a more effective computational approach to curate the data. This allowed the IBS-CAPP to search for DFSZ axions at 3.5 times the rate of the ADMX setup.

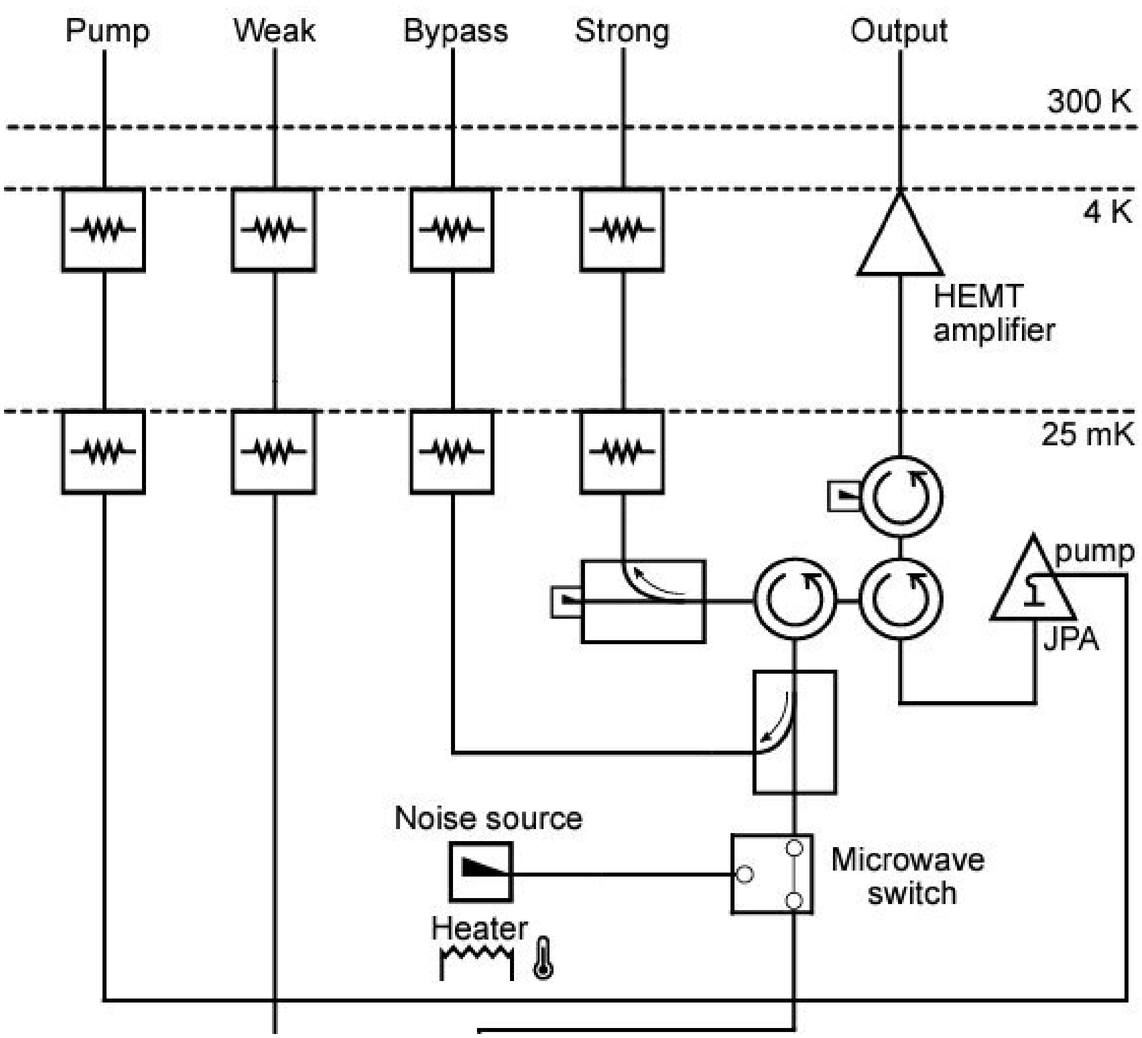

Figure 4. CAPP-12TB receiver diagram. Credit: Institute for Basic Science

The latest publication by the IBS-CAPP details the demonstration of their new setup for DFSZ axion search from March 1 to March 18, 2022. As a result, the group was able to exclude axion dark matter around 4.55 μeV at DFSZ sensitivity. The findings are published in the journal *Physical Review Letters*.

"Discovery of axion will allow us to understand up to 32% of the mass-energy of the universe, up from 5% offered by the current Standard Model," states research fellow KO Byeong Rok of the IBS-CAPP. He added, "We plan to take advantage of the blazingly fast speed of our experimental setup to quickly search for DFSZ axions at the wide frequency ranges of 1 to 2 GHz."

It is hoped that the discovery of axion will support the Grand Unification Theory (GUT), which unites the three fundamental forces—strong, weak, and electromagnetism. It is believed that the three fundamental forces were united and indistinguishable at the earliest moment after the Big Bang, under conditions orders of magnitudes higher than achievable in the Large Hadron Collider today. It is hoped that the GUT will serve as a stepping stone to the coveted Theory of Everything (TOE) that has eluded theoretical physicists all these years.

Director Yannis SEMERTZIDIS of IBS-CAPP said, "We are highly grateful for all the funding and support that the Institute for Basic Science and South Korean taxpayers provided for this project. It is thanks to them that South Korea now hosts the most advanced axion search experimental facility in the world. If axion exists, I have no doubt it will be found right here in South Korea."

More information: Andrew K. Yi et al, Axion Dark Matter Search around 4.55 μeV with Dine-Fischler-Srednicki-Zhitnitskii Sensitivity, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.130.071002

Provided by Institute for Basic Science