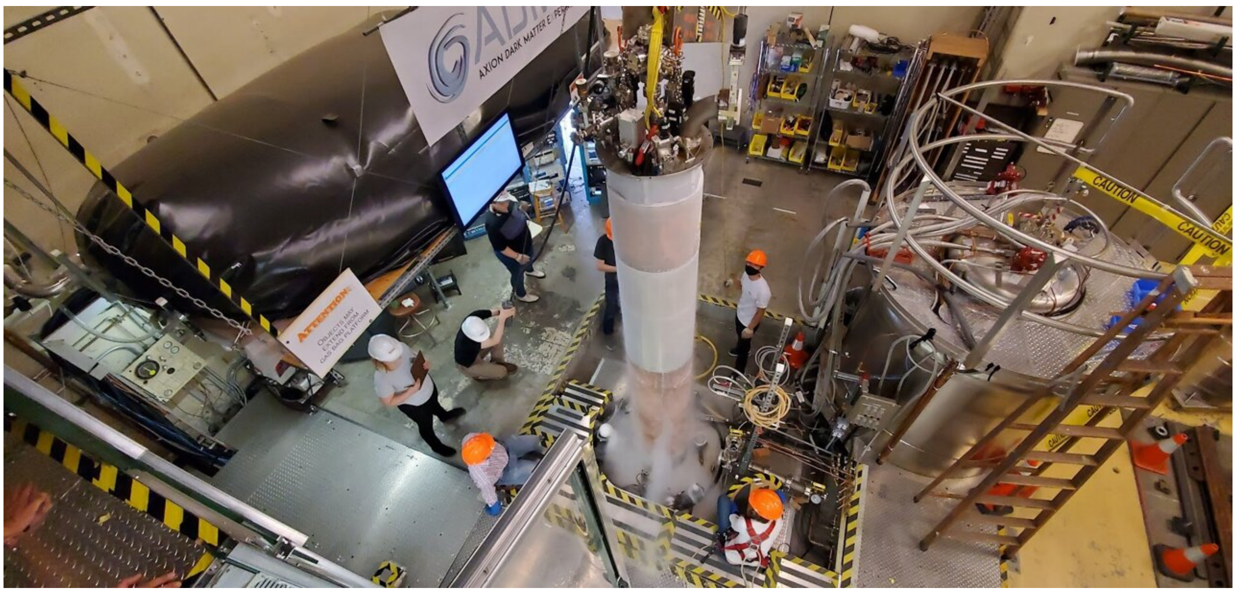
Examining the results of new dark matter searches by the PandaX-4T and ADMX collaborations

February 16 2022, by Ingrid Fadelli



The ADMX apparatus right after extracting from the magnet bore. It was cooled by Liquid Nitrogen, so it makes cold mist. The left big black bag and right big reservoir are the parts of liquid Helium recycling system. Credit: ADMX Collaboration.

Physicists have predicted the existence of dark matter, a material that does not absorb, emit or reflect light, for decades. While there is now significant evidence hinting to the existence of dark matter in the universe, as it was never directed detected before its composition remains unknown.

In recent years, researchers worldwide have made different hypotheses about the composition of this elusive material and tried to test them experimentally. Many have suggested that it could be comprised of new and previously unobserved types of elementary particles, such as axions and weakly interactive massive particles (WIMPs).

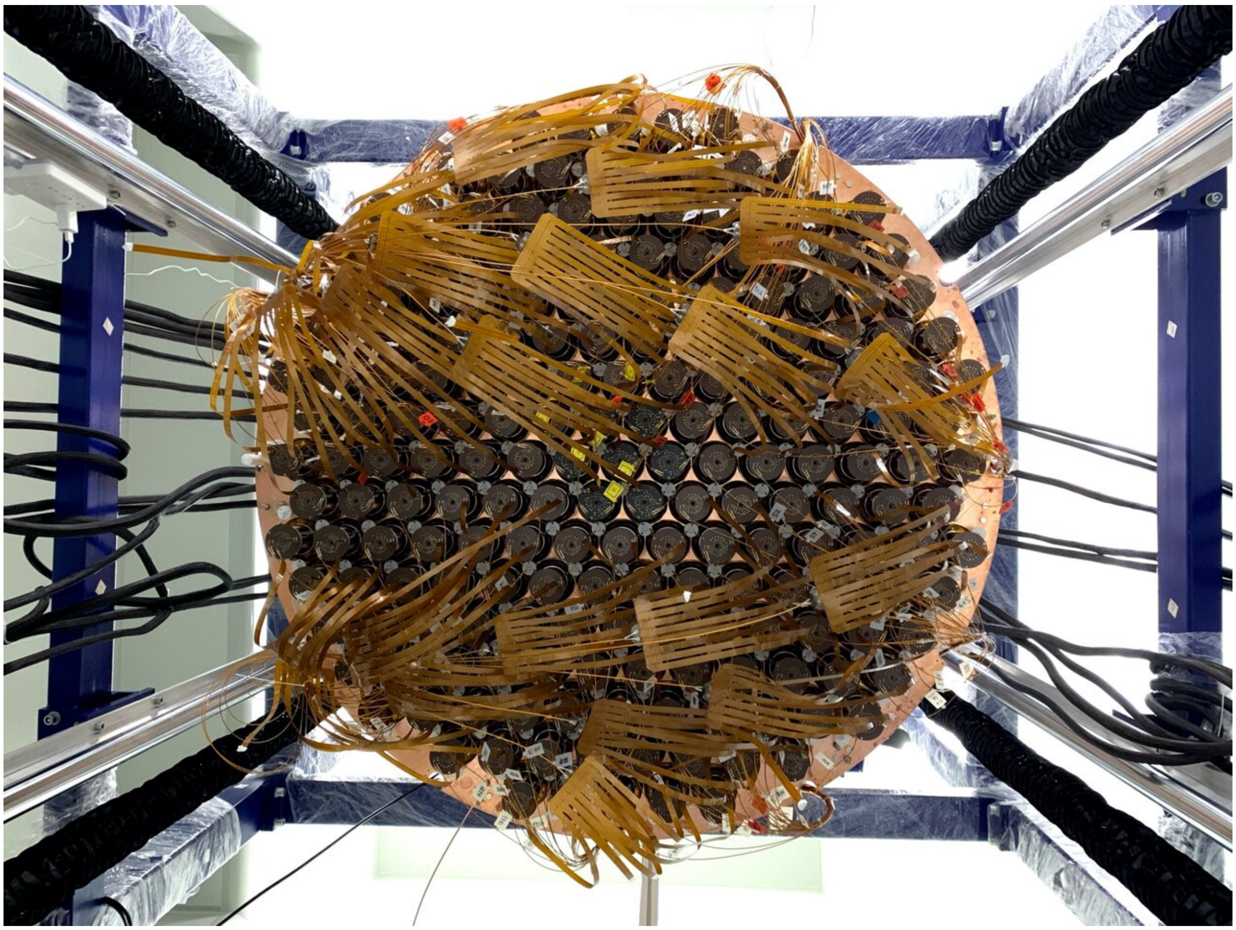
A few weeks ago, two large research collaborations, the PandaX-4T and the ADMX Collaborations, published the results of two new dark matter searches based on different hypothesis. In their study, featured in *Physical Review Letters*, the PandaX-4T Collaboration tried searching for signs of a new elementary particle in data collected using a time projection chamber at the China Jinping Underground Laboratory (CJPL), the deepest underground lab in world.

"One of the most promising particle candidates for dark matter is the so-called, WIMP, which naturally explains the observed relic density of dark matter today," Qing Lin told Phys.org, on behalf of the whole PandaX-4T Collaboration. "WIMPs could have very weak interactions with matter, allowing them to be searched for in laboratory experiments."

The primary objective of the recent work by the PandaX-4T Collaboration was to search for the energy deposition resulting from a direct interaction between WIMP particles and target nuclei. To do this, they used a detector located deep underground, which is characterized by a very low energy threshold (keV) and low radioactive background.

"The technique employed by our detector is the so-called dual-phase xenon time projection chamber (TPC), which collects both light and charge signals of an energy deposition," Lin explained. "The data was collected at CJPL from November 2020 to April 2021."

The PandaX-4T dark matter detector is one of the largest in the world. The detector was built from scratch in the newly expanded CJPL-II facility, over a short period of time starting from 2018.



A plot of PMT arrays in the TPC detector of the PandaX-4T experiment. Credit: PandaX-4T Collaboration

"We had a very successful commissioning run and produced the first scientific dataset," Lin said. "In our paper, we reported a search for WIMP and the best constraint for it up to now. It indicates the interaction of WIMP with nucleon could be feebler than constraints given by previous experiments."

Around the same time as the PandaX-4T Collaboration published its results, a large research team called the ADMX Collaboration was outlining the results of a different search for dark matter. In their study, also featured in *Physical Review Letters*, the ADMX Collaboration specifically searched for axions, another promising candidate for dark matter, using a haloscope-based detector.

"Axions were first proposed to solve the strong CP problem (Peccei/Quinn/Weinberg/Wilczek)," Tatsumi Nitta, one of the members of the ADMX Collaboration, told Phys.org. "ADMX is based around the idea of an axion haloscope, as proposed by Pierre Sikivie not long after axions were suggested as also being a dark matter candidate."

The ADMX Collaboration was founded in 1993, but it published its first results five years later. These initial findings, which were among the most promising predictions of the existence of axions, allowed them to set constraints on the so-called KSVZ model. Ultimately, however, the team hoped to test constraints for the DFSZ model, which requires 10 times less power than the KSVZ model.

"In 2018, we finally reached the DFSZ model by installing a quantum amplifier at around 650 MHz," Nitta explained. "Axions can be anywhere between sub-GHz and THz, so the next thing to do is obviously scan over higher frequencies. With the 2019 result and this result, we replaced several components to suit the higher frequency signals and successfully completed scanning over the 650-1,020 MHz frequency range."

Theoretical predictions suggest that axions are converted into a strong magnetic field by electromagnetic waves. The power of these waves is expected to be very low, around the yocto (10^{-24}) Watt level. This is approximately ~10^{-12} less power than what a car radio can pick up.

To pick up this signal, the AMDX collaboration uses a 7.5 T superconducting magnet. Their highly sensitive detector is based on quantum amplifiers, such as the Josephson Parametric Amplifier, a class of technologies that are widely used in the field of quantum computing.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The ADMX apparatus hanging for upgrades. The bottom brown (copper color) cylinder is a cavity where axion could be converted with photons. Silver cylinder is a Helium reservoir to keep magnet cool. Quantum electronics is hidden in innermost of the Helium reservoir. Credit: ADMX Collaboration.

"The frequency of the electromagnetic wave corresponds to axion mass, which is around 1 GHz for our current target axions," Nitta said. "This is between FM radio and Wifi frequencies. The signal is a fixed frequency peak from axions, above a white noise background from the black-body radiation (like why the Sun is bright. In our case, the temperature is so low so very small power is expected)."

As part of their recent study, Nitta and his colleagues analyzed over 200,000 spectra, searching for a tiny frequency peak signal. Nonetheless, they were unable to detect any axions within the specific frequency range they examined.

"Our findings mean that if axions have the predicted KSVZ coupling, we can exclude axions of these masses from making up all of dark matter," Nitta added. "This lets us know to search elsewhere, because the theory gives a range of frequencies we need to explore. We demonstrated an efficient way of determining a peak in a spectrum is axion or not (it is mentioned like TM010 or TM011 modes)."

After publishing their paper, the team implemented several changes and upgrades on their experimental methods and equipment. In their future work, they plan to try searching for axions in the same frequency range again, to exclude the possibility of DFSZ model- axions. Subsequently, they also hope to explore higher frequencies, in the hope of finally detecting axion dark matter.

Meanwhile, the PandaX-4T Collaboration is also planning additional dark matter searches. To improve their chances of detecting interactions between WIMP particles and target nuclei, they will first work on improving the sensitivity of their detector.

"The PandaX-4T is expected to improve current sensitivity of dark matter search by one order of magnitude and scan a large range of unexplored parameter space with a nominal 6-ton year exposure," Lin said. "Meanwhile, as a multi-purpose experiment, PandaX-4T is also aimed to study neutrino physics including majorana neutrinos, solar neutrinos, supernova neutrinos, etc."

More information: Dark matter search results from the PandaX-4T commissioning run. *Physical Review Letters*(2021). DOI: 10.1103/PhysRevLett.127.261802

Search for invisible axion dark matter in the 3.3-4.2 μeV mass range. *Physical Review Letters*(2021). DOI: 10.1103/PhysRevLett.127.261803

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