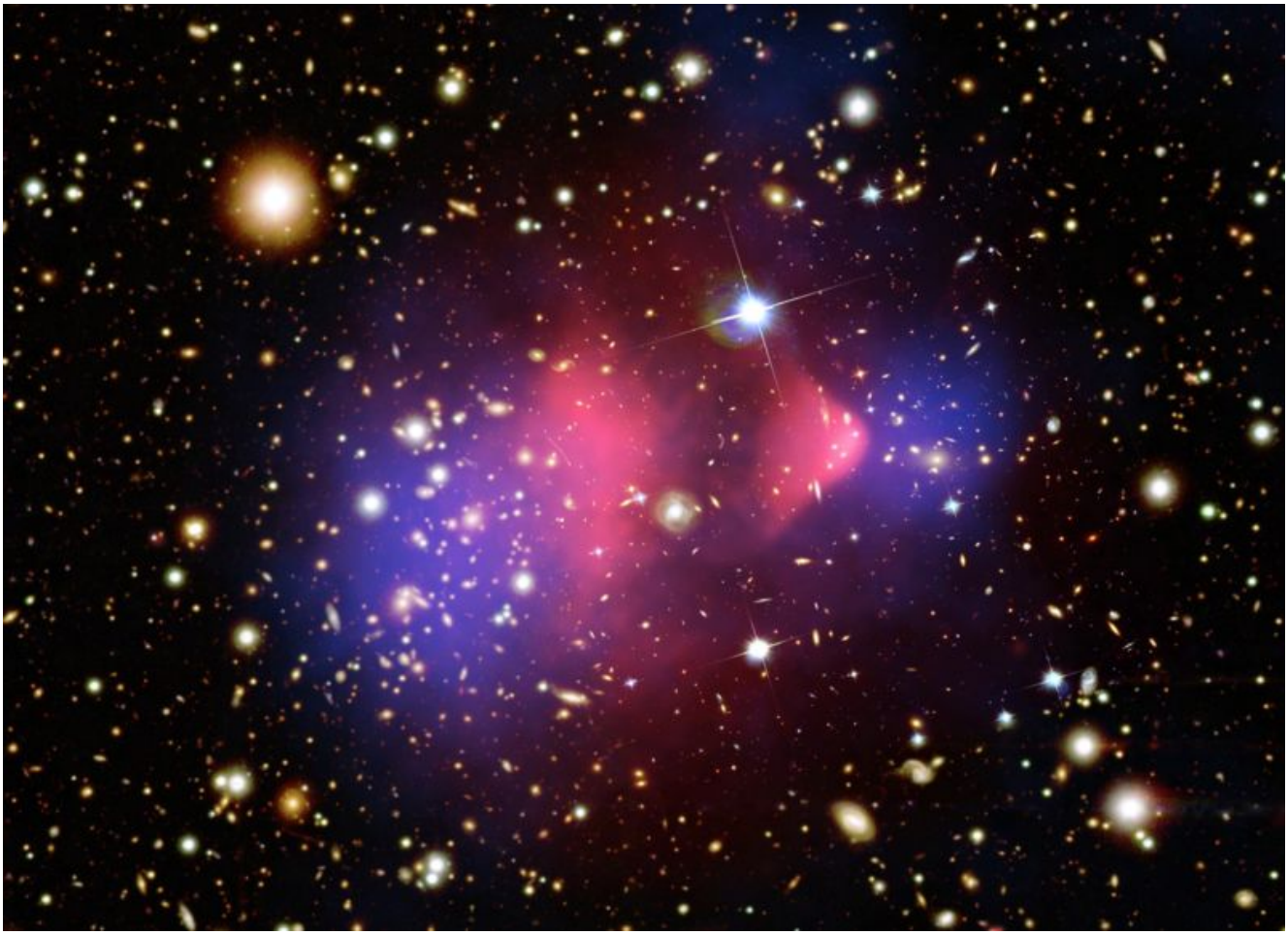
Physicists propose listening for dark matter with plasma-based “axion radio”



Enlarge / The Bullet Cluster is widely viewed as a clear demonstration of the existence of dark matter.

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Dark matter is the mysterious substance that comprises about 23 percent of all the mass in our universe, but thus far it has eluded physicists’ many attempts to directly detect it. Maybe instead of looking for a dark matter particle, they

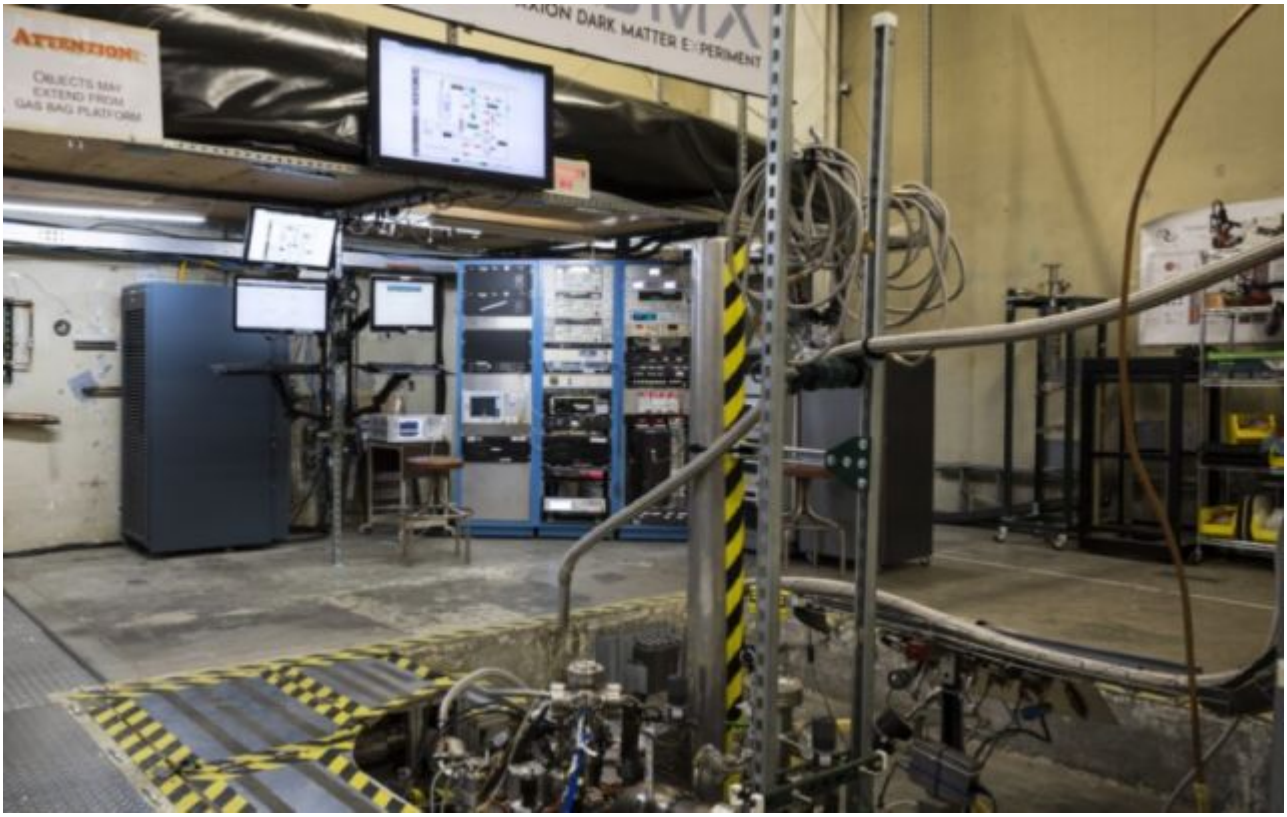
should be looking for something more akin to a wave—a hypothetical dark matter candidate known as an axion.

In that case, perhaps we should be "listening" for the dark matter. Physicists at Stockholm University and the Max Planck Institute of Physics have proposed a novel design for an "axion radio" that employs cold plasmas (gases or liquids of charged particles) to do just that in a recent paper in Physical Review Letters.

"Finding the axion is a bit like tuning a radio: you have to tune your antenna until you pick up the right frequency," said co-author Alexander Millar, a postdoc at Stockholm University. "Rather than music, experimentalists would be rewarded with 'hearing' the dark matter that the Earth is traveling through."

Much of the hunt for dark matter thus far has focused on so-called weakly interacting massive particles, or WIMPs. There was very good theoretical reason to focus on that mass range, most notably the concept of supersymmetry, whereby every particle in the Standard Model should have a "super-partner" that is heavier and in the opposite class (fermion or boson). For example, an electron (in the fermion class) would have a boson super-partner called the "selectron." One or more of those super-partners might make up the dark matter.

But all the experiments hunting for dark matter have repeatedly come up empty, and the available parameter space within the WIMP-y mass range is shrinking rapidly. Physicists know they are getting very close to the "neutrino floor," where the detection technology will become so sensitive, and will be picking up so many random neutrinos, that picking out a dark matter signal in all the noise will become much harder.



Enlarge / The ADMX experiment uses a resonant cavity haloscope to detect axions.
Mark Stone/University of Washington

Enter the axion, the second-most promising candidate for dark matter. According to quantum mechanics, particles can exhibit wavelike behavior as well as particle characteristics. So an axion would behave more like a wave (or wave packet) than a particle, and the size of the wave packets is inversely proportional to their mass. That means these very light particles don't necessarily need to be tiny. The downside is that they interact even more weakly with regular matter than WIMPS, so they cannot be produced in large colliders—one current method for detecting WIMPs.

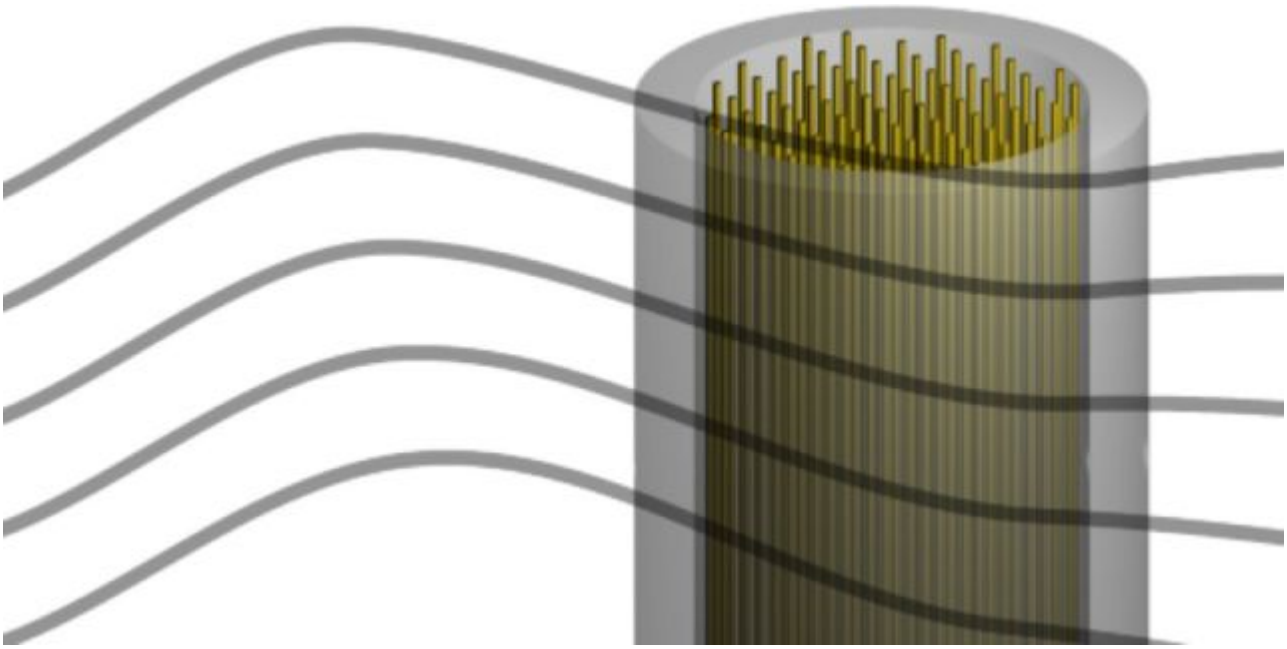
Physicists don't know what the axion's mass might be, so there's a broad parameter space in which to search, and no single instrument can cover all of it, according to co-author Matthew Lawson, also a postdoc at Stockholm University. That's why physicists have been developing all kinds of smaller experiments for detecting axions, from atomic clocks and resonating bars, to shining lasers at walls on the off-chance a bit of dark matter seeps through the other side. Yet most

instruments to date are capable of detecting axions only within a very limited mass range.

That includes experiments—most notably ADMX and HAYSTAC—that employ resonate cavity haloscopes, instruments that use a strong magnetic field to convert dark matter axions to detectable microwave photons. The biggest challenge with conventional haloscopes is that the mass range they can detect depends on the size of the instrument. So to reach higher frequencies, or mass ranges, with haloscopes, you need increasingly smaller volumes. So ADMX and HAYSTAC struggle with pushing their detection capability above roughly 6GHz.

Lawson *et al*. have come up with an innovative design for a tunable plasma-based haloscope. Their proposed instrument exploits the fact that axions inside a strong magnetic field will generate their own small electric field. This in turn drives oscillations in the plasma, amplifying the signal.

The team compares the improvement in sensitivity to the difference between a walkie-talkie and a radio broadcast tower. “The cool thing about our idea is that its resonance has nothing to do with its physical extent,” said Lawson. “So even at higher frequencies, you can have a large volume that you’re harvesting dark matter from.”



Enlarge / Stockholm University researchers proposed a new instrument for searching dark matter axions using tunable plasmas.
Alexander Millar/Stockholm University

That same interaction can also produce a plasmon, a quasiparticle that "is like a sound wave, except instead of rattling a nuclei or atoms around, you're rattling around electrons," said Lawson. In order to produce plasmons, the plasma's characteristic frequency must match the axion's frequency (which is determined by its mass). So you have to be able to create "tunable" plasmas.

Lawson and his cohorts propose this can be done via a "wire metamaterial:" an array of thin parallel wires within a cylinder, surrounded by a powerful external magnetic field. The metamaterial works much like a transformer. The wires couple to each other inductively, such that setting up a current in one will produce a current in the other. The frequency can thus be tuned by changing the spacing between the wires in the array, making it possible to search for axions in a much broader range.

For detection purposes, a cold plasma is preferable. "Typically with any kind of dark matter detection experiment, your signal is going to be phenomenally small," said Lawson. "So you want as low noise environment as possible. Any time you have a hot plasma it glows." (That is, a hot plasma generates photons, adding unwanted noise to the system.) "Without the cold plasma, axions cannot efficiently convert into light," he said. "The plasma plays a dual role, both creating an environment which allows for efficient conversion, and providing a resonant plasmon to collect the energy of the converted dark matter."

At the moment, Lawson *et al.*'s design is theoretical, but several experimental groups are actively working on building prototypes. "The fact that the experimental community has latched onto this idea so quickly is very exciting and

promising for building a full-scale experiment," said Millar.

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