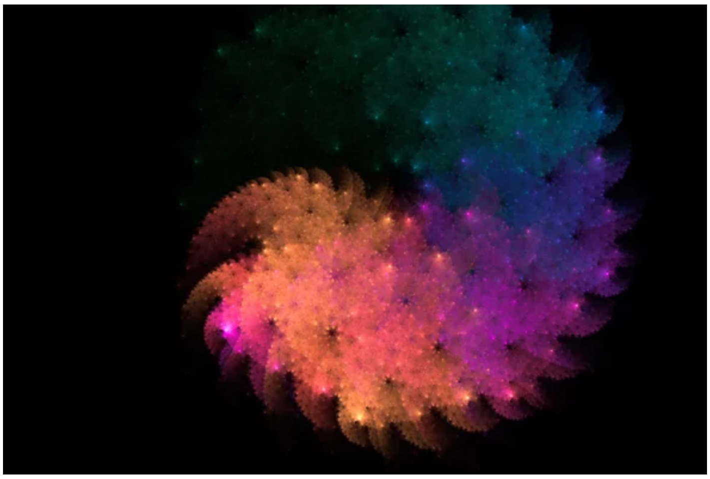
PHYSICS

Possibility of Dark Bosons Entices Physicists

Hints of anomalous activity in heavy isotopes could be clues to new physics

By Daniel Garisto on September 30, 2020



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Physicists are on the hunt for dark forces. These forces are not as ominous as they sound: “dark” simply refers to the fact that no one has observed them before. In this case, they would act between neutrons and electrons.

One path to investigating dark forces involves using lasers to make precision measurements of isotopes (atoms of an element possessing different numbers of neutrons). If there is a dark force working behind the scenes, it could affect an isotope’s energy levels—discrete regions around the atom’s nucleus where its electrons exist.

Now two teams have independently performed the most precise measurements of this type. Their findings, reported this month in *Physical Review Letters,* are mixed: One group, led by researchers at Aarhus University in Denmark, analyzed calcium isotopes and saw no deviation from predictions. But the other team, led by scientists at the Massachusetts Institute of Technology, used ytterbium isotopes and found a deviation in the electron energy levels with “three sigma” significance—that is, assuming no dark forces or other factors, the result would happen once every 370 times because of random chance.

If there is a dark force at work here, physicists believe it would be carried by a force-carrying particle: a boson. "'Dark boson' is not well-defined," says Elina Fuchs, a physicist at Fermi National Accelerator Laboratory near Chicago and a member of the Aarhus-led team. "It's just a very feebly interacting particle that can be connected to matter." These efforts are searches for a dark force, not dark matter—the mysterious stuff that composes 85 percent of the matter in the universe. Such a dark boson could be an important component of dark matter, or it could simply be part of a larger "dark sector" of particles.

The Aarhus-led study's results do not rule out dark forces, but the M.I.T.-led team's findings do not confirm them. Typically, physicists will not assert a discovery has been made until a result's statistical significance reaches five sigma (in this case, a one-in-1.7-million chance). The M.I.T.-led researchers are quick to clarify that they are skeptical their result is linked to dark forces. Most likely, the deviation is instead because of some as yet uncalculated nuclear force——nothing outside the Standard Model, the theory that governs known particles and forces, minus gravity.

"We're not claiming to have discovered anything like a new particle," says Vladan Vuletić, a physicist at M.I.T. and a co-author of the paper. "Most likely, we are measuring new nuclear physics, but there is the possibility of something else going on."

The hunt for dark forces is part of a broader search for new physics. Hints, such as the existence of dark matter, the mystery of why neutrinos have mass and the relative weakness of gravity, suggest that there may be particles and forces beyond what physicists have accounted for in the Standard Model.

Traditionally, these searches have occurred at higher energies using particle accelerators such as the Large Hadron Collider at CERN near Geneva to create new particles in the wreckage of extreme subatomic smashups. Building these behemoth experiments consumes inordinate amounts of time and money, so researchers have been looking for alternative ways to probe for new physics.

The novel class of precision measurements instead look for new physics at low energies by making sure everything is in order—checking that dark forces are not hiding in small changes between isotopes, for example. There is no reason to think that such forces could be hiding in isotope data—but then again, there is no reason not to.

"We are completely in the dark," Vuletić says. "It's a completely different way of working. We're poking here and there and hoping that, somewhere, we discover something."

KING OF PLOTS

In 1963 William King, a physicist then at the University of Oxford, noticed an interesting pattern. When he compared the energy levels of isotopes against one another, he saw they formed a straight line on a graph. Such King plots, as they became known, have long been important to nuclear physicists. But researchers have only recently begun using them to search for new physics.

Two years ago another paper in *Physical Review Letters* put forward the possibility of finding dark bosons in King plots. A dark boson that linked electrons and neutrons would shift energy levels from isotope to isotope, the authors suggested. For example, a calcium isotope with 20 neutrons should have essentially the same energy levels as one with 22 neutrons because electrons are not attracted to neutral neutrons. But a dark boson could create a small attraction, shifting the electron's energy levels in a discernible fashion.

These quests for dark bosons are different from dark matter searches. Researchers are not looking for real, incoming particles. Instead they are scanning for the effects of a virtual particle on the isotopes—similar to investigations involving magnetic fields—says Joonseok Hur, a Ph.D. student at M.I.T. and co-lead author of the new ytterbium study. The signal of that subtle deviation should strengthen as more isotopes are compared with one another.

"It's a very efficient way to constrain new physics," says Yotam Soreq, a physicist now at the Technion–Israel Institute of Technology in Haifa and a co-author of the 2018 *Physical Review Letters* paper. "Once you see deviation from linearity, like the M.I.T. group sees at some level of significance, then you need to start to think, very, very carefully, 'What is this effect?'"

Not all nonlinear effects arise from new physics, of course. For example, an isotope's additional neutrons can deform its nucleus or can even be oddly distributed throughout. These kinds of changes would be difficult to distinguish from a dark boson, in part because it is hard to precisely calculate energy levels for the bulky isotopes used in such searches. As elements get bigger, predicting the electron energy levels with classical computers requires exponentially more calculating power.

To look for nonlinearities in King plots in the two new studies, both teams used a similar approach: The researchers placed a single atom in a laser trap to hold it in place. Then they used additional lasers to probe the isotope, varying the laser's frequency until they found the exact energy levels—a little like tuning a radio frequency through static until you stumble on a channel.

The results appeared straightforward enough, forming an uncannily exact and unwavering King plot. "We did the experiment, and we ended up having the straightest line I ever measured in my life," says Michael Drewsen, a physicist at Aarhus and co-author of the new calcium study.

The M.I.T.-led team, on the other hand, saw energy levels that were 500 to 1,000 hertz away from predictions, registering as a small curve in the King plot. (The levels were measured in hertz because the frequency of light is proportional to its energy.) The group's experiment, however, could not distinguish Standard Model nonlinearities from new physics nonlinearities, so the results are inconclusive.

Previous data from astrophysical observations and particle physics experiments have put stronger bounds on the strength of a dark force between electrons and neutrons. But if the researchers can improve the precision of their energy level measurement by a few orders of magnitude—which both teams say they believe is possible—the search for dark forces via King plots will become truly competitive. Increased precision would also allow them to corroborate or challenge the so-called Atomki anomaly, which suggests the existence of a dark boson that is about 34 times heavier than the mass of an electron.

Potential future improvements could emerge from including more highly charged isotopes, additional elements, short-lived isotopes and even the quantum entanglement of two isotopes within an ion trap. “It takes time. It’s not trivial work at all,” Soreq says. “But [this technique] can be improved much, much further.”

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Daniel Garisto is a freelance science journalist covering advances in physics and other natural sciences. His writing has appeared in *Nature News*, *Science News*, *Undark*, and elsewhere.

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