Stanford physicist suggests looking for dark matter in unusual places

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Physicist Peter Graham recently received a Breakthrough New Horizons Prize for his novel approach to particle physics. Credit: L.A. Cicero

For decades, particle physics has been the domain of massive colliders that whip particles around at high speeds and smash them into one another while teams of thousands observe the results. These kinds of experiments have produced great insights into forces and particles that make up the physical world.

But Stanford physicist Peter Graham is advocating a much different approach – one that could be faster and cheaper than massive colliders, and that may be able to detect previously elusive forms of physics like dark matter.

Graham pointed out that colliders cost tens of billions of dollars and come along so rarely that there might only be one new collider built in his lifetime. His approach evokes a time when physics could be carried out on a tabletop by one or two people and produce results in just a few years.

"It's going back to that in some ways, but using very different types of technologies and different approaches," said Graham, who is an assistant professor of physics. "It's a new direction for looking for the most basic laws of nature."

Graham, who is also a collaborator with the elementary particle physics division at SLAC National Accelerator Laboratory, recently received a Breakthrough New Horizons in Physics Prize for his novel direction, which he hopes more people will join. He spoke with Stanford Report about why physics needs new types of experiments, what dark matter might be and how he hopes to detect it.

You've said that your experiments explore new physics. What does that mean?

The standard model of particle physics is everything we've discovered. It explains almost every experiment ever done over gigantic scales, from nuclei to galaxies. There's really just a very few things it doesn't explain, which we call new physics. We know there is stuff out there beyond what we've seen, like dark matter, and new fundamental laws. Those are the things we are trying to discover.

Dark matter is one form of new physics you might be able to detect. Can you explain what dark matter is and why physicists believe it exists?

Initially, people realized that there's much more gravity pulling in on galaxies than they could account for. Either the laws of gravity were wrong, which was possible, or there was something else that we don't know about pulling on the galaxies. Either way, you can't explain it with what we know.

There's now a lot of evidence that our understanding of gravity isn't wrong, and instead there's some new kind of stuff that physicists have named dark matter. It's been a major goal in physics to understand dark matter and come up with new types of experiments to try to detect it. But you have to have some guesses about what it might be if you are going to find it. It's a universal point in science that you have to have some idea what you are looking for in order to know how to go about looking for it.

What are some of the theories about what dark matter might be?

There is a lot of evidence for two candidates, called WIMPs and axions. You can look for WIMPs [weakly interacting massive particles] with more traditional techniques, like the giant colliders, and that attracted a lot of attention.

There was just one experiment looking for axions and it only looked at part of the possible axion spectrum. It was a scary scenario that axions might be the dark matter and there might be no way to detect them. Axions are very difficult to search for because they don't interact much with our experiments.

Dark matter could also be some crazy new kind of particle, or a combination of WIMPs and axions, or even collections of black holes. We don't know.

What motivated you to think about alternate ways of exploring new physics?

Part of the motivation is that the big colliders are important but they are also getting expensive to build. In addition, we are realizing that some new theories about dark matter really couldn't be discovered at colliders.

My work has been to take techniques from other fields of physics and use them in particle physics. The Breakthrough Prize is really nice because it brings a stamp of approval and could really help us get this new experimental direction going.

Can you give me an example of one type of experiment you've designed?

People had thought about one approach to detect axion dark matter and it did a good job for higher mass axions, but could not possibly see lower mass axions. We came up with a new technique to detect low mass axions. It involved combining NMR [nuclear magnetic resonance], which is commonly used in medical applications, and magnetometry, which is a very precise tool for measuring magnetic fields. We use NMR to amplify the axion signal so that the magnetometer can pick it up.

We've already started building this experiment, and it could generate results in a few years. It's very exciting because these kinds of experiments can produce results on short time scales.

Why is it important to explore these new frontiers in physics?

Humanity has always stared up at the stars and wondered why we are here. These kinds of questions, like the nature of dark matter, tell us about the birth of the universe, why the whole universe is here.

But a part of it for me is also that I want to be making some contribution. One example of how basic physics helps people came from quantum mechanics. I'm sure at the time they thought it was a pure physics exercise and had no relation to human health. Well, we learned quantum mechanics and now we have MRI machines and PET scans. I would say that's a really important lesson. Humans are creative and we do find ways to use new information.

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