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NOVA

What it's like to run the world's best dark matter detector

Physicist **Chamkaur Ghag** is on a mission to find the 85 per cent of the universe's matter we haven't yet identified. He tells Leah Crane how the hunt is going and what it would mean if we found it

DEEP underground in the middle of South Dakota, the most sensitive dark matter detector on Earth sits quietly waiting. This is the LUX-ZEPLIN (LZ) experiment, the central part of which is a large tank of liquid xenon. Physicist Chamkaur Ghag at University College London is one of the leaders of the huge scientific collaboration working on the experiment. Its mission is to find the 85 per cent of the universe's matter that we haven't yet identified.

Today, Ghag and his fellow hunters stand at something of a turning point in the search for this elusive substance. There are loose plans to build a detector called XLZD, which would be several times the size of LZ and even more sensitive. But if both of these fail to sniff out the goods, it will force physicists to reconsider what they think dark matter is made from.

As Ghag says, that may mean the next generation of dark matter detectors won't be underground behemoths, but surprisingly small and humble affairs. In fact, he explains in advance of his upcoming talk at New Scientist Live this October, he has already built one such prototype.

Leah Crane: First things first, why is dark matter so important?

Chamkaur Ghag: On the one hand, we have particles and atoms and everything that particle physics tells us about how the constituents of matter come together. On the other hand, we have our understanding of gravity. It may seem like this is all good, but if you try to put gravity and particle physics together, there's a big problem: our galaxy shouldn't be here. It's holding itself together with gravity that seems to come from matter that we can't see. And it's not just a little glue. Some 85 per cent of the matter in the universe is this so-called dark matter.

Why have we been hunting for it for so long and not found anything?

At the moment, we think dark matter is probably made of what we call WIMPs, or weakly interacting massive particles, which were born in the early universe. If so, it would only very rarely interact with other particles and even then give off an extremely feeble signature. So, we need huge detectors. The larger they are, the better the chance that a dark matter particle going through it will interact. And they have to be really quiet so they can be sensitive to the tiny recoils of particles hit by dark matter if it interacts – even the slightest vibration could mask the signal.

We talk about a theoretical phase space for dark matter, which means the range of possible masses and properties that this stuff could have. We have already ruled out some of this space. So we have to keep getting deeper underground, with larger and larger detectors, to approach the promised land: the theoretical phase space where particles of dark matter could still exist.

It is a ridiculously painstaking craft. With our detector, we had to make sure there was almost no background noise. For instance, most metals produce tiny amounts of radioactivity, so we had to work hard to minimise that problem in our construction materials. LZ is the lowest background noise, most radio-pure instrument on the planet.

So LZ is the most sensitive detector that we have right now – how does it work?

Essentially, it's a double-walled Thermos flask a few metres wide and a few metres tall that contains 7 tonnes of liquid xenon. In this flask, the xenon is in a highly reflective barrel, and it's viewed from the top and bottom by light sensors. And then there's a final touch: we have an electric field across this barrel. If a WIMP comes in and hits a xenon nucleus, it would produce a small flash of light, a few photons. But because we've got an electric field, we pull away the electrons [freed up in the collision] from the nucleus, and also produce a separate, brighter flash.

This means that anything that happens in our detector gives us two light signals. Where that happens tells us the position of the event, and then the amount of light from the primary flash versus the secondary flash tells us the microphysics of whether this was a WIMP that came in and hit the nucleus or something else, like say a gamma ray. We have it all a mile underground to shield from cosmic rays, and

then we have it in a water tank to shield it from the rock itself.

It is such a complicated endeavour. What was the hardest part in getting it to work?

There was a similar, smaller predecessor experiment called LUX and we knew what we needed to do to get the instrument 10 times more sensitive. Actually doing it was challenging, if satisfying. For me, the hardest part was making sure the instrument was as clean and quiet as it needed to be. If you take LZ and you unfurl it, it's huge, it's a football pitch-sized area and we can only tolerate a single gram of dust on that whole surface.

What's it like to work at that ultra-clean detector so far underground?

It's a former gold mine, so there's this very industrial-looking environment. You get your hard hats on and you go down a mile, and then there's a bit of a trek to the lab. Once you're into the lab, you can forget where you are. Then you're into clean-room garb and it's computers and equipment and whatnot – it's just a lab with no windows. But the journey down is sort of otherworldly.

Up to now, WIMPs have been the dominant candidate for dark matter. But with nobody spotting any evidence of them yet, at what point do we say WIMPs are dead?

I think if we reach the point where XLZD, the larger detector we have planned, has been built and has not seen them. If we are having to explore beyond the range of that instrument, it gets hard for the cookie-cutter standard WIMP to exist. But until that point, they're still crazy alive. That territory between what we have explored so far and where XLZD will get, that's the fun stuff.

You have developed a completely different and far smaller detector for dark matter. Tell us about that.

What we have is a 150-nanometre-wide glass bead that we levitate with lasers so that it acts as a highly sensitive force detector. What's nice is that we can tell if it moves in any of the three dimensions. So, we can say, 'OK, something has pinged it from a particular direction'. That's great, because it means that now you can start to rule out all your terrestrial backgrounds, like radioactive decay from materials underground.

That's quite a departure from the huge detectors like LZ. What's the rationale behind building that – and will we see more small detectors?

The large underground experiments are huge,



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The LUX-ZEPLIN dark matter detector was built in an old gold mine

so they are super sensitive – but in a sense, the fact that they are so large actually limits their sensitivity. Let's say that whenever a dark matter particle hits my xenon detector, it produces 10 photons. I can easily detect all of those if my xenon tank is small, but if I have a huge tank, they have to bounce around all over the place and I might only catch three of them.

Now, let's imagine that any time a dark matter particle hits my detector, it only ever produces two photons in the first place. In that scenario, the maximal signal you can get from a detector akin to LZ diminishes. That's why there is now a push to look for lower mass dark matter particles that are outside of the range of LZ – and that means turning to other sorts of detectors.

Let's say we actually find dark matter. What does that mean for physics and the universe?

It solves two problems. This is the obvious one: what is this missing 85 per cent of the matter in our universe? But it would do that in a way that doesn't involve the standard model of particle physics, our essential list of the building blocks of reality.

So, if you find dark matter, you have your first peek outside this model. We have no solid evidence for anything specific outside of the standard model yet – nothing at all. This would be that first beam of light into the room. ■



Leah Crane is a features editor at *New Scientist*



Hear more from Chamkaur Ghag at this year's New Scientist Live. On Saturday 18 October, he will delve into the fascinating world of dark matter detection and describe the search for this elusive stuff in the Milky Way.

For more information, visit newscientist.com/nslmag