The author is beginning her second year in the DOE NNSA SSGF at Rice University. This was the winning entry in the 2021 Essay Slam.

Into the Darkness

By Sophia Farrell

Where there is darkness, there is light. We hear this proverb echoed in epic stories like *The Lord of the Rings* and *The Odyssey*, in prayers and throughout generations of old tales. But for me – and 180 fellow scientists around the world – the timeless struggle between darkness and light is literal.

Miles below the Earth's surface, near a centuries-old mountain town in Italy, lies the world's cleanest, darkest and largest vat of liquid xenon: We call it the XENONnT experiment. Housing almost 9,000 kilograms – or about 10 tons – of ultrapure xenon, our beautiful experiment's many superlatives are all the product of a mission to detect dark matter. Dark matter makes up five times more of the universe than all the other matter that we know and love, like stars and planets. Normal matter interacts with light; it's why we see stars in the sky, or why you can read the words on this page. However, dark matter interacts with normal matter so rarely that we cannot see it from Earth or space. Instead, we go underground, hoping that there the world is so dark that dark matter might just shine brighter.

Our subterranean lab is quiet, cold and damp. It's also free from nearly all the atmosphere's radiation, thanks to the halting force of the mountains that shield our xenon. Here, we set up an ingenious detector to observe what particles interact with xenon far underground. There are the usual-suspect interactions, like background radiation from the detector materials or errant ultra-energetic particles from the atmosphere. But occasionally something unexpected happens.

The work of a physicist under this mountain is anything but glamorous. After you don a hardhat, steel-toed boots and, if you are working on the detector itself, a hazmat suit, you enter a delicate ecosystem of intricate electronics, cryogenic pumps, purification systems and, of course, the xenon detector itself. Yet except for the fortunate few (myself included) who helped build the detector, most XENONnT scientists may never see their own detector. We shield the detector from the radiation in the mountain and in our own bodies by sealing the device inside a three-story-tall water tank. Our detector rests contentedly while we buzz about, monitoring its many systems. The pumps, labyrinthian in their complexity, hum in unison; their rhythmic melody to us means, "We aren't broken!" We work in similar fashion, flowing along, intertwined throughout the lab. There is always an expert and a student, though each of us is a student in many respects. Working together on site keeps us informed and constantly learning. The more we can learn about the detector's every aspect, the better we can look for dark matter.

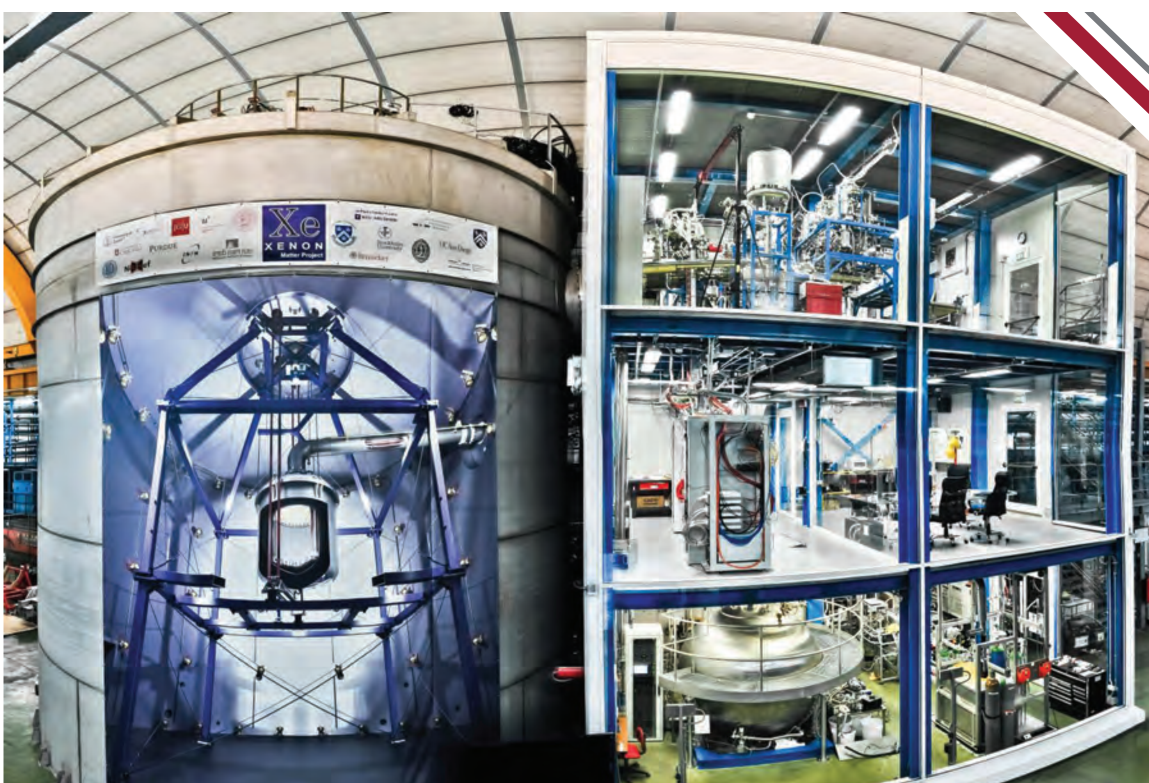
We see signals from our detector with cameras that record specks of light. We have to infer for every interaction the likelihood that it came from dark matter interacting with xenon. This is where I enter the scene. We can't see into our detector lest we contaminate it. Instead, we must observe its behavior with non-invasive sensors. Each signal is unique, imparting to the sensors hints of its origin via a digital fingerprint. I translate these signals into physics.

We reconstruct each fingerprint to determine whether a dark-matter particle left it behind or if it's from a blithe neutron or some other particle. So far, only known particles have come out to play in our xenon, but observing what we know is not always a bad thing. It offers glimpses of particles behaving in new ways, and that has led to discoveries like the rarest nuclear decay ever recorded, that of xenon-124.

Our gentle giant, XENONnT, provides us hints at not only what dark matter is and is not but also how our known universe and its constituents behave. This helps us reconstruct the universe's past and infer our Earth's state today. Our detector tells us acutely about its surroundings. Particles that pass through us invisibly are blinding beams to the xenon atoms, allowing us to put our dark matter detector to practical use in many particle physics applications.

But the story is not all dark and light. There are gray areas as well. Recently, we saw a curious fingerprint, a slight excess of signal, that led to more questions than answers. It was unlike anything we had predicted. Perhaps nature is playing games with us. Or maybe it is humanity's first glimpse of dark matter. Only time, and the 180 passionate scientists devoted to this project, will tell.

We must always remind ourselves of our purpose, especially in times of darkness. Why go to these lengths? Why push xenon, physics and even ourselves past where we haven't gone before? For me, the reward of discovery is worth the struggle, the light brighter and more precious when it is seen in darkness. If we can see the dark matter, we know the story of our universe, and our place in it, that much more clearly. In pushing the bounds of dark matter to their limits, we push ourselves, too. Perhaps that pursuit is equally worthwhile.



The three-story-tall XENONnT dark matter experiment, cocooned inside a mountain in Italy. *XENON Collaboration.*