Dark Matter

Interviewee: Dr. Miriam Diamond

Sourced from her profile, as featured on the Arthur B. McDonald Institute website, Miriam's primary research area is low-mass dark matter searches, as a member of the SuperCDMS direct-detection experiment at SNOLAB. Her team at UofT focuses on Data acquisition, data quality management and low mass dark matter analysis.

Miriam started her career in physics right out of high school, when she was hired as a data analyst for the original SNO project. Several physicists, including Art McDonald on the SNO team, helped guide Miriam's further education decisions and grant applications.

At Perimeter Institute, Miriam worked with the theorists and would visit the experimentalists and became interested in the work they were doing. She developed a love of hands-on work with particle detectors, a passion that she followed into a Ph.D. in experimental physics at UofT. At the time, the LHC had just finished Run 1, and there were several dark matter prospects on the horizon. Miriam joined the dark matter search at ATLAS, and by the time she was finishing her Ph.D., the ATLAS team had covered much of the dark matter parameter space that she favoured at the time. SuperCDMS (Cryogenic Dark Matter Search) is a direct-detection experiment that looks for interactions of dark matter in cryogenic germanium and silicon detectors equipped with sensors for the thermal energy of particle interactions. The low detection thresholds provide sensitivity to a variety of lower-mass dark matter candidates. SuperCDMS operated in an underground laboratory in Soudan, Minnesota until 2015; now the collaboration is building an even more powerful version of the experiment in SNOLAB. First operations are expected in 2020, and a CUTE (Cryogenic Underground Test Experiment) facility is opening this year to support the detector development and characterization.

Bio

In the summer of my first year of undergraduate studies, I was hired as a research intern at Carleton University, doing data analysis for the Sudbury Neutrino Observatory (SNO) collaboration. I continued my work at SNO over the next several summers; the collaboration eventually shared the 2016 Breakthrough Prize in Fundamental Physics with four other neutrino experiments. I obtained my MSc through the Perimeter Scholars International program at the Perimeter Institute for Theoretical Physics in Waterloo. There, I was inspired to continue to further graduate studies in high energy physics from inspiring encounters with several of the physicists I most admire and my research experiences in the particle physics group.

For my PhD, I decided to return to the experimental side, searching for dark matter in the ATLAS detector – while I found theory fascinating, I missed the hands-on work with real data. I spent several months on-site at CERN, and being in the ATLAS Control Room for the first stable particle collisions of Run 2 (as an on-call expert for the Beam Conditions Monitor) was one of the greatest thrills of my life. My analysis work focused mainly on dark photon searches using “lepton-jets” produced in the particle collisions. As a post-doc at SLAC National Accelerator Laboratory, I continued looking for dark photons — but this time on the Heavy Photon Search experiment, which is still ongoing. The experiment involves shooting a high-energy electron beam into a fixed tungsten target, in hopes of producing dark photons and then detecting their electron-positron decay products in a highly sensitive silicon tracker and electromagnetic calorimeter. I am now a Principal Investigator on yet another type of dark matter search, the SuperCDMS direct-detection experiment.

Universe and Dark Matter Facts

- The universe is made up of at least two kinds of matter. Primarily, there's the material we can detect, which astronomers call "baryonic" matter. It's thought of as "ordinary" matter because it's made of protons and neutrons, which can be measured. Baryonic matter includes stars and galaxies, plus all the objects they contain.
- Dark matter makes up about 85 percent of the total matter in the universe, accounting for more than five times as much as all ordinary matter.
- Dark matter played an important role in the formation of galaxies.

- Researchers use astronomical surveys to build maps of the location of dark matter in the universe based on how the light from distant galaxies bends as it travels to us.

Broad Overview

As explained on CERN's website: Unlike normal matter, dark matter does not interact with the electromagnetic force. This means it does not absorb, reflect or emit light, making it extremely hard to spot. In fact, researchers have been able to infer the existence of dark matter only from the gravitational effect it seems to have on visible matter. Dark matter seems to outweigh visible matter roughly six to one, making up about 27% of the universe.

The matter we know and that makes up all stars and galaxies only accounts for 5% of the content of the universe! But what is dark matter? One idea is that it could contain "supersymmetric particles" – hypothesized particles that are partners to those already known in the Standard Model.

Side bar: The Standard Model, according to CERN's website, includes the theories and discoveries of thousands of physicists since the 1930s have resulted in a remarkable insight into the fundamental structure of matter: everything in the universe is found to be made from a few basic building blocks called fundamental particles, governed by four fundamental forces. Our best understanding of how these particles and three of the forces are related to each other is encapsulated in the Standard Model of particle physics. Developed in the early 1970s, it has successfully explained almost all experimental results and precisely predicted a wide variety of phenomena. Over time and through many experiments, the Standard Model has become established as a well-tested physics theory.

Experiments at the Large Hadron Collider (LHC) may provide more direct clues about dark matter. Many theories say the dark matter particles would be light enough to be produced at the LHC. If they were created at the LHC, they would escape through the detectors unnoticed. However, they would carry away energy and momentum, so physicists could infer their existence from the amount of energy and momentum “missing” after a collision. Dark matter candidates arise frequently in theories that suggest physics beyond the Standard Model, such as supersymmetry and extra dimensions. One theory suggests the existence of a “Hidden Valley”, a parallel world made of dark matter having very little in common with matter we know. If one of these theories proved to be true, it could help scientists gain a better understanding of the composition of our universe and, in particular, how galaxies hold together.

Coining the term “dark matter”

The term dark matter was coined in 1933 by Fritz Zwicky of the California Institute of Technology to describe the unseen matter that must dominate one feature of the universe—the Coma Galaxy Cluster. The galaxies in the Coma Cluster were moving too quickly for as much mass as there appeared to be, and dark matter was a potential explanation.

In the 1970s, Vera Rubin of the Carnegie Institution found evidence for dark matter in her research on galaxy rotation. But the nature of dark matter remains a mystery.

Composition of Dark Matter

The likely sources of dark matter divide into two rough categories: cold dark matter (CDM) and hot dark matter (HDM). The category names don't refer to temperatures, though; instead, they refer to speed, with a 'cold' particle being one that is moving well below the speed of light.

Cold Dark Matter

Sourced from a *ThoughtCo* article:

CDM is a kind of dark matter that, if it exists, moves slowly compared to the speed of light. It is thought to have been present in the universe since the very beginning and has very likely influenced the growth and evolution of galaxies. as well as the formation of the first stars. Astronomers and physicists think that it's most likely some exotic particle that hasn't yet been detected. It very likely has some very specific properties:

It would have to lack interaction with the electromagnetic force. This is fairly obvious since dark matter is dark. Therefore it doesn't interact with, reflect, or radiate any type of energy in the electromagnetic spectrum.

However, any candidate particle that makes up cold dark matter would have to take into account that it has to interact with a gravitational field. For proof of this, astronomers have noticed that dark matter accumulations in galaxy clusters wield a gravitational influence on light from more distant objects that happen to be passing by. This so-called "gravitational lensing effect" has been observed many times.

Hot Dark Matter

Sourced from *Cosmos*, an astronomy encyclopedia, HDM requires a particle with near-zero mass (neutrinos are a prime example; axions, or supersymmetric particles are others). The Special Theory of Relativity requires that nearly massless particles move at speeds very close to the speed of light. However HDM does not fully account for the large-scale structure of galaxies observed in the universe. Using neutrinos as an example, their highly relativistic velocities would tend to smooth out fluctuations in the matter density as they propagated through the universe. They would be good at forming very large structures like superclusters, but not smaller galaxies.