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Cosmic Perspective

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Designing and fabricating its complex components, Perera and his students construct the world's smallest Fourier Transform Spectrometer.

Thushara Perera and his students are hard at work building a device designed to better grasp how cosmic dust gave rise to planetary systems and perhaps to life itself.

Story by KIM HILL
Lab photos by MARC FEATHERLY

When Fiona Breyer ’17 and Lunjun (Simon) Liu ’17 were teenagers looking at the night sky from their homes on two different continents, astrophysics seemed so exotic and exciting.
So the students were a bit nonplussed when their in-the-trenches experiences in astrophysics began not by looking up, but by drilling down — learning to use a milling machine, lathe, drill press, and other vital but rather unsexy pieces of equipment in the machine shops in the Center for Natural Science basement.

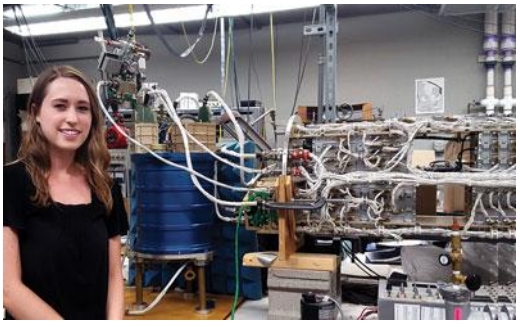
The two are among a half-dozen students contributing to a project led by Associate Professor of Physics Thushara Perera to design instrumentation that will help scientists learn more about cosmic dust. Once regarded as a nuisance by astronomers because it absorbs the visible light from objects, cosmic dust is now recognized for the role it plays in the evolution of galaxies, stars, and planetary systems. Though not yet fully understood, cosmic dust is also thought to have an integral role in the chemical activity giving rise to complex molecules, some of which may be the precursors of amino acids, the building blocks of life.

Perera realized there is no one facility in the world dedicated solely to the study of cosmic dust candidates, or man-made items mimicking the dust’s chemical and physical properties. At large research facilities, an apparatus is rigged together for testing such candidates and then taken apart for other uses, says Perera, leading to systematic errors.

Perera reasoned that a dedicated system for studying cosmic dust — one that utilized the principles of observational cosmology — would greatly reduce such errors. “The whole goal of observational cosmology is to reduce systematic errors when you are looking at the sky,” he adds. “So our system is built from a different perspective.” The National Science Foundation (NSF) recognized the novelty of this approach and awarded Perera a grant for the project.
At the project’s center is a spectrometer. Its basic function is to take in light, break it into its spectral components, send those components through cosmic dust samples, record the amount of light transmitted through each sample as a function of wavelength, and display the data through a computer program.

Among the instruments Perera and his students are building is a Fourier Transform Spectrometer (FTS), which makes use of an innovative concept put forth by Dale Fixsen, a research scientist with NASA’s Goddard Space Flight Center. “I exchanged about three emails with Fixsen and we did the rest,” Perera says. When they are finished, Perera and his students will have constructed the world’s smallest FTS.

What’s most unique about the project is the design — the compact FTS is coupled to a cryostat. Essentially a very cold refrigerator (referred to in the lab as “the fridge”), the cryostat can cool samples to 4 Kelvin, or –452 degrees Fahrenheit. The fridge can be used to match the temperatures of actual astronomical dust clouds (10-50 Kelvin). The structure that holds the fridge, along with the pumping/vacuum station, were mostly built and installed by IWU physics students. So were most of the thermometers, associated cables and electronics, as well as special insulation within the fridge, which also includes a bolometer, or millimeter-wavelength light detector. This sensitive instrument measures radiant energy.



Experience in Perera's lab helped Breyer '17 earn an NSF research fellowship at the University of Wisconsin, where her focus was a spectrometer used for suborbital observations.

While Perera led the way in devising the spectrometer — from working out the mathematical formula to writing the source

code to cut metal for the ellipsoidal mirrors inside the spectrometer —his students made major contributions. Showing these components to a visitor, the professor ticks off some of the many advances made by past and current students:

Kyle O'Shea '16 took Perera's CAD designs for the FTS and machined most of the necessary parts to high precision using IWU's milling machine. He also implemented a system to control the FTS's moving mirror, and used Wesleyan's 3D printers to make several items, including an adapter for the vacuum enclosure of the FTS. O'Shea is now a Ph.D. student in mechanical engineering at Michigan State University, where he's working on new technology for 3D printing.

Hansheng (Jason) Chen '17 designed a robust optical window for the cryostat, so that a wide spectral range of light can pass into the fridge without compromising the vacuum within. After completing the design — which was fabricated at the University of Illinois — Chen made changes and machined additional parts to help install the optical window. This fall, he will enter a graduate program in theoretical astrophysics at the University of California, Davis.

Huy Do '16 — now completing his 3:2 dual degree in electrical engineering at Washington University in St. Louis— was an early contributor to the project. Do's work on the bolometer electronics and filter wheel mechanics built a foundation for the progress that has been made on the instrument thus far.

As the project's lead student this past year, Lunjun Liu played a major role in developing and testing a unique filter wheel housed in the fridge. This wheel holds and switches dust samples, allowing researchers to study up to eight different samples in one cooldown. Liu machined shafts, pulleys, and dozens of other mechanical parts in the CNS machine shop.

Liu's first challenge was to learn basic skills and safety protocols needed to work with these tools. "I had no experience in any kind of building before coming to IWU," said Liu, a native of Wuhan, China. "I was not expecting that would be something that would be necessary for an astrophysicist." But as he built the part, tested it, refined it, and tested it again in a seemingly endless process, he began to grasp the importance of such routine tasks to the final outcome.

Liu believes his "in-the-trenches" experience in the IWU lab has given him an important advantage. Last summer he was selected for Caltech's competitive Summer Undergraduate Research Fellowship. Because he was familiar with cryostats, detectors and electronics from his work at Illinois Wesleyan, Liu entered the Caltech lab confident of his abilities.

"At Caltech I observed other students not fully understanding the inner workings of the equipment, because they are not building things step by step, without understanding every concept of every device," says Liu, who is returning to Caltech for a year to assist with deployment of one of his projects there before entering graduate school in astronomy at the University of Illinois. "I was able to provide my point of view to fine-tune a device, for example, to provide a better outcome."

Sharing with the World

"At temperatures this cold, so much can go wrong," says Ronan Dorsey '18, who joined Perera's lab group in May 2016 and worked through the summer, spending much of that time machining parts for a "light pipe" within the cryostat that carries light from the outside to the dust samples inside the fridge.

Perera and Dorsey make adjustments to the vacuum station connected to the cryostat. Construction is scheduled for completion this summer, when the NSF grant's funding cycle comes to a close.

"The machining can seem menial," Dorsey admits, "but it's so important to take your time and just do it slow so you get it right. Or, at least, as much as you can before you test it. And then you go back to the machine shop when you figure out you did it wrong." Breyer's introduction to the project was equally unglamorous. When she joined as a sophomore, she said her tasks involved screwing parts that had already been machined onto the body, or applying oil to keep the machining functioning smoothly. "I had no idea what I was doing at first," she admits with a laugh. "It takes a while to really understand the project."

Soon, however, Perera tasked Breyer with automating logging of the fridge's temperature and detector data with LabVIEW, a graphical language used for data acquisition and instrument control. In the summer of 2015, Breyer worked in Perera's lab to collect data as the spectrometer was being calibrated.

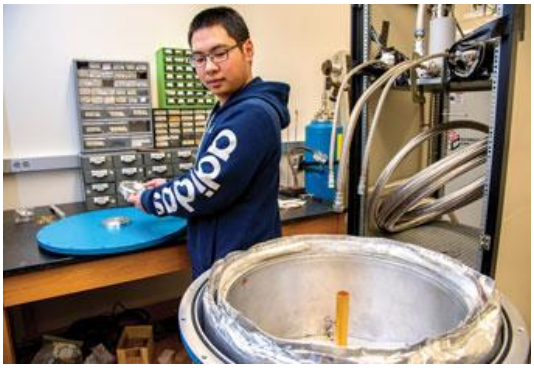
"My program would take data points every minute for something like 15 hours, store it, and then we'd review it the next morning," she says. According to Perera, Breyer also played a large role in structuring and organizing the inside of the cryostat. Breyer believes this lab research experience helped her secure a spot for a nationally competitive NSF Research Experiences for Undergraduates internship in 2016.

"Going into the summer research experience at the University of Wisconsin–Madison, I felt so much more confident about my abilities," Breyer notes.

"Dr. Perera has always believed in me, even when I didn't believe in myself, and he's made me feel confident in my abilities to do lab work, to be a physicist, and to be successful."

The chance to work alongside a faculty member, building a device from the ground up in hopes of learning more about the origins of planetary systems, is not lost on the students.

"Spending four or five hours a day for a whole summer with Dr. Perera, working one-on-one on this project, is not something I would find at a big university," Dorsey observes. "Working directly with a physicist of Dr. Perera's caliber has been the most rewarding thing about this entire project."



Chen '17 prepares to install an optical window he designed into the cryostat. After graduating from IWU, he will enter a graduate program in theoretical astrophysics at the University of California, Davis.

Dorsey has become the 'go-to-guy' in daily operations as Perera and his group have conducted three cooldowns in order to improve the bolometer's performance. After a successful cooldown of the cryostat in February, the next step is to test and troubleshoot the entire system. Construction is scheduled for completion this summer, when the NSF grant's funding cycle comes to a close.

Perera said that to his knowledge, there has been no other successful operation of a detector of this kind using a 'dry' cooling mechanism that employs gas pulses, rather than liquid helium, to cool. The only other FTS Perera knows of that's remotely similar to the one at Illinois Wesleyan is housed in the lab of a colleague at the University of Michigan.

Despite the daily challenges and troubleshooting necessary to get a new instrument of such complexity up and running, Perera anticipates the satisfaction of soon being able to share the IWU group's work with the world. First up is an academic paper on the project's instrumentation, projected for later this year. And he looks forward to the day — soon, he hopes — when the device is fully functioning in its purpose to aid astronomers and astrophysicists in the quest to better understand the nature of cosmic dust.

"There is still much we don't know about dust-obscured environments," says Perera. "But knowing about the properties of the dust tells us how that dust was created, and that's a piece of information about how a planetary system evolved or how a new planetary system was made."

Perera notes the field of astronomy is currently preoccupied with asking the question of how life came to be, with the role of cosmic dust explored within that question. "I can understand that, because as a child in Sri Lanka, my interest in

science was born, in part, that way as well," he recalls. "Looking at the stars, and wondering if there was someone looking back from another planet."

Perera and his students continue pursuing the answers to those questions, but stand proud of what their work has already added to the growing body of knowledge for all those who still seek.

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