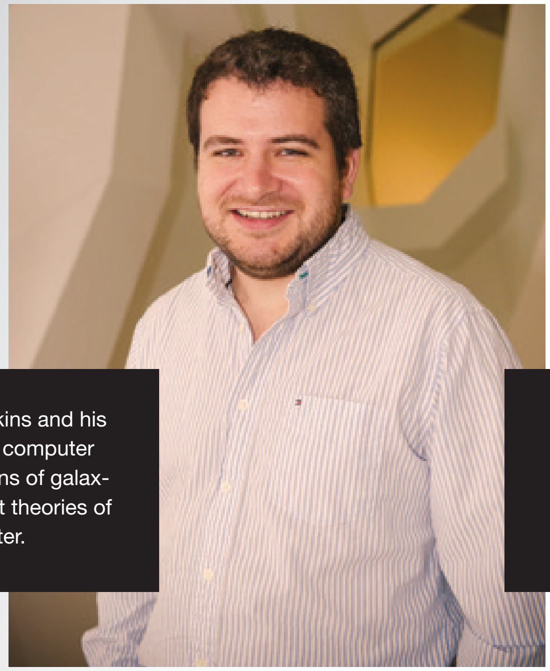
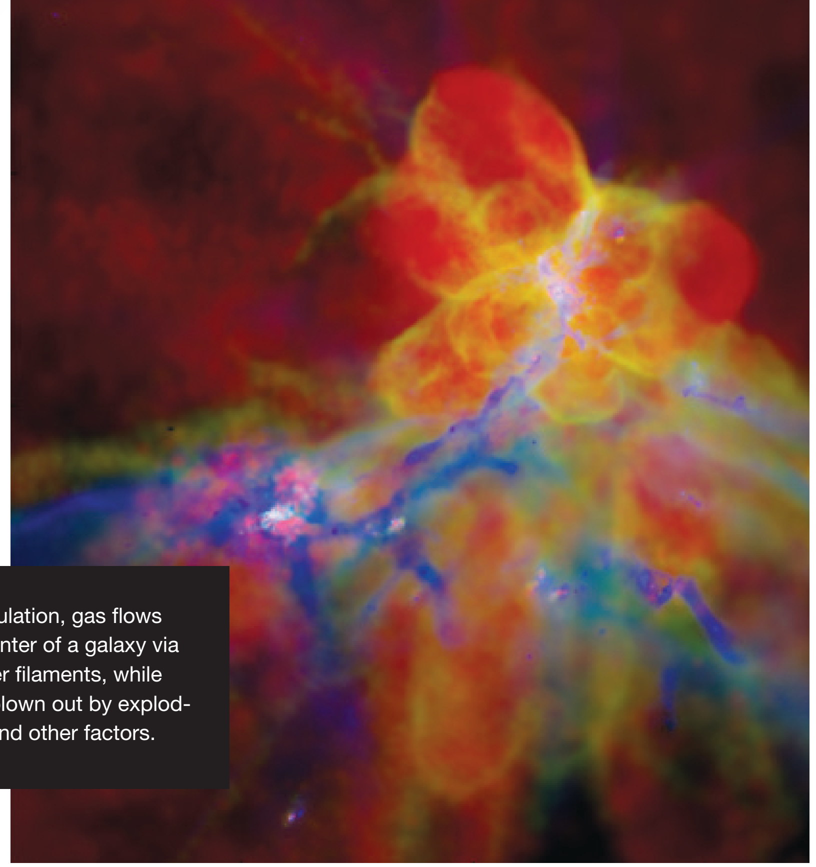


Phil Hopkins and his team run computer simulations of galaxies to test theories of dark matter.



In this simulation, gas flows into the center of a galaxy via dark matter filaments, while matter is blown out by exploding stars and other factors.

to explain the dark matter abundance. In addition, a theory known as supersymmetry (which states that every particle has a partner with a complementary spin) predicts partner particles, one of which could be a WIMP. But, over the years, evidence for supersymmetry has failed to materialize.

"There had been hope for many years that if we saw dark matter it would be a hint that supersymmetry exists, but people are getting less and less convinced. Kathryn is one of the people who has strongly advocated for looking at other models, given that supersymmetry has not turned out to be discovered yet," says Golwala. "That's been one of the big motivations for wanting to look down at the mass range that we're looking at. Twenty years ago, if you told someone you were looking for dark matter at 1 giga-eV, they might say, 'Why are you doing that? There's no supersymmetric particle down at 1 giga-eV.' And now, 20 years later, as far as we know, there's no supersymmetry, so we had better pay attention to these other models. The nice thing about SuperCDMS is that we are looking for WIMPs and the hidden sector."

By adding dark matter physics into computer simulations of galaxies, researchers can make predictions about features that telescopes might observe in the future.

In addition to contributing to SuperCDMS, Golwala is working on tabletop experiments specifically designed to uncover the hidden-sector particles. He says he pays close attention to Zurek's guidance on what types of interactions to look for between dark matter and normal matter. "Kathryn is a theorist, and I am an experimentalist. She says, 'This is the thing you should build in order to look for this model of dark matter.' I take her ideas and say, 'OK, we are going to build an experiment that can do that.'"

Just Add Dark Matter

Outside the lab, there are other ways to probe the hidden sector. Phil Hopkins and his team have embraced the various new dark matter ideas and folded them into their computer simulations of galaxies and the universe. Like baking a batch of cookies, researchers can mix and match cosmic ingredients in a computer simulation and see what arises. If a resulting galaxy looks like the real thing, then scientists know they are closer to understanding its ingredients.

"If you assume that most matter in the universe is dark matter, and that dark matter interacts only with gravity, then it is actually pretty simple to set up your computer simulation," says Hopkins. "You have one force, gravity, and you let everything evolve from there."

Recently, Hopkins and his students have refined this simple simulation to include hidden-sector physics. He says his research serves as a bridge between that of Zurek and Golwala, in that Zurek comes up with the theories, Hopkins tests them in computers to help refine the physics, and Golwala looks for the actual particles. In the galaxy simulations, the hidden sector dark matter is "harder to squish" because of its self-interacting properties, explains Hopkins, and this trait ultimately affects the properties of galaxies. The team's computer creations allow them to make predictions about the structure of galaxies on fine scales, which next-generation telescopes, such as the upcoming Vera C. Rubin Observatory, scheduled to begin operations in Chile in 2022, should be able to resolve.

"You can imagine a whole dark universe or this hidden sector where all sorts of things are happening underneath normal matter or 'under the hood,' as you might say. What we have tried to do is ask, 'What are the astrophysical consequences?'" says Hopkins.

Several other Caltech researchers are also on a quest to uncover the nature of dark matter, including cosmologists who study its effects on vast scales that span the history of the universe, as well as particle physicists who search for dark matter candidates produced in high-energy colliders such as CERN's Large Hadron Collider, or LHC. Cristián Peña (MS '15, PhD '17), a Lederman Postdoctoral Fellow at Fermilab and a research scientist with the High Energy Physics group and INQNET (INtelligent Quantum NEtworks and Technologies) at Caltech, was among the first, in 2016, to attempt to discover dark matter in high-energy proton-proton collisions at the LHC. Those searches for dark matter were made with data collected by the Compact Muon Solenoid instrument.

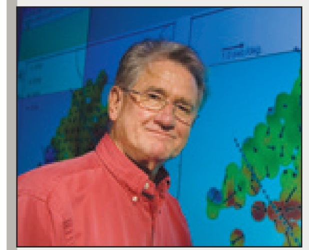
Now, Peña is developing quantum-sensing experiments to detect dark matter. The state-of-the-art sensors he is using are being developed as part of a quantum internet project involving INQNET in collaboration with Fermilab, JPL, and the National Institute of Standards and Technology, among others. INQNET was founded in 2017 with AT&T and is led by Maria Spiropulu, Caltech's Shang-Yi Ch'en Professor of Physics. A research thrust of this program focuses on building quantum-internet prototypes including both fiber-optic quantum links and optical communication through the air, between sites at Caltech and JPL as well as other quantum network test beds at Fermilab. The optimized sensors developed with JPL for this program are also well-suited to detect very-low-mass dark matter and, as Peña says, any "feeble interactions" of hidden-sector states beyond the Standard Model of particle physics.

"Quantum sensing is an emerging research area at the intersection between particle physics and quantum information science and technology," he says.

While most researchers agree that finding dark matter is a long shot, they feel confident that the pursuit, and all the science and technology that has been and will be acquired along the way, is worth the journey. After all, we know that dark matter exists and, as Carroll says, it is "not really all that mysterious." When Carroll explains dark matter to the public, he has them imagine that our moon is made of dark matter and thus invisible. "We would still experience the moon's tides on Earth even though we couldn't see the moon. We know dark matter is there, we just can't see it." [C]

In Memoriam

Read more about their lives at **magazine.caltech.edu/post/in-memoriam**



Donald V. Helmberger 1938-2020

Donald V. Helmberger, who ran the Caltech Seismological Laboratory from 1998 to 2003, passed away on August 13 at the age of 82. Helmberger joined the Caltech faculty as an assistant professor in 1970 and was named Smits Family Professor of Geophysics in 2000. His primary research interests involved seismic-wave propagation and the use of waveforms to recover information about earthquake characteristics as well as the earth's structure.

Masakazu (Mark) Konishi 1933-2020

Masakazu (Mark) Konishi, the Bing Professor of Behavioral Biology, Emeritus, passed away on July 23. He was 87 years old. Konishi was renowned for his work on the neuroscience underlying the behavior of owls and songbirds. His team worked extensively on the auditory systems of barn owls, which use their acute hearing to home in on prey on the ground, even in total darkness. He also theorized and then showed experimentally how the brains of songbirds learn and produce song.

James (Jim) Morgan 1932–2020

James (Jim) Morgan, the Marvin L. Goldberger Professor of Environmental Engineering Science, Emeritus, at Caltech, who previously served as dean of students and later as vice president for student affairs, passed away on September 19 at the age of 88. Morgan, who joined Caltech's faculty in 1965, focused his research on the chemistry of aquatic environments and water treatment, and in particular on the scientific bases for establishing criteria and standards for water-quality protection.